Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: Final Project Report

F. H. Page, B. D. Chang, D. A. Greenberg

Science Branch, Maritimes Region
Fisheries and Oceans Canada
Biological Station
531 Brandy Cove Road, St. Andrews, NB
E5B 2L9

2004

Canadian Technical Report of Fisheries and Aquatic Sciences 2543

Fisheries and Oceans Canada | Pêches et Océans Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact parait au-dessus du résumé de chaque rapport. Les rapports techniques sont résumé dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développe-ment, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of
Fisheries and Aquatic Sciences 2543

104-07474/

July 2004

Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: Final Project Report

by

F.H. Page[1], B.D. Chang[1], D.A. Greenberg[2]

[1]Fisheries and Oceans Canada
Science Branch, Maritimes Region
Biological Station
531 Brandy Cove Road, St. Andrews, NB E5B 2L9

[2]Fisheries and Oceans Canada
Science Branch, Maritimes Region
Bedford Institute of Oceanography
Dartmouth, NS

This is the two hundred and fifty-fourth Technical Report
of the Biological Station, St. Andrews, NB

© Her Majesty the Queen in Right of Canada, 2004

Cat. No. Fs 97-6/2543E ISSN 0706-6457

Correct citation for this publication:

Page, F.H., Chang, B.D., and Greenberg, D.A. 2004. Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: final project report. Can. Tech. Rep. Fish. Aquat. Sci. 2543: vi + 47 p.

ABSTRACT

Page, F.H., Chang, B.D., and Greenberg, D.A. 2004. Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: final project report. Can. Tech. Rep. Fish. Aquat. Sci. 2543: vi + 47 p.

The Fish Health and Oceanography Project received funding from the DFO Aquaculture Collaborative Research and Development Program (ACRDP) in late 2001. The project's main goal was to enhance understanding of the water circulation and water transport pathways within the Long Pond Bay area of southern Grand Manan and to use this to help assess the influence of the water circulation pattern on fish health and bay management concerns in the area. This report summarizes the project's findings. It also includes the presentations given at the final meeting of the project, held on 17 February 2004.

The project included collection of field data and the development of a circulation and particle transport model. Field data included the release of CAST (Convertible Accurate Surface Tracker) drifters and the deployment of InterOcean S4 and RDI Workhorse ADCP (Acoustic Doppler Current Profiling) current meters. The results from the field data were compared to the computer model results. The computer model is a three-dimensional finite element model, with resolution of 50-100 m in the southern Grand Manan area. In this model, currents are driven by the M_2 lunar tide.

In general, agreement between the field data and model predictions was reasonably close. Where there were discrepancies, these could be rationalized. For example, most model runs did not include the effect of wind on the circulation and yet the winds sometimes had an effect on the trajectory of drifters. In one area, local knowledge advised of the existence of a localised magnetic disturbance which made compass readings in the area unreliable and hence could have affected S4 current meter readings gathered in the specific area of the disturbance. Minor inaccuracies in the model coastline and bathymetry and the effects of fish farms on water currents (the model did not include the presence of fish farms although the physical presence of fish cages probably affects the water flow in the vicinity of the farm) may have degraded comparisons between observed and modelled currents in a few cases.

One of the main questions addressed by the project concerned the amount of water exchange between the sole even year-class farm (site MF-303, located in northern Long Pond Bay) and its nearest neighbour (site MF-403, located about 2 km due south). The project results indicated that tidally induced water movement in the area of site MF-303 was largely in the east-west direction. This is perpendicular to the north-south axis connecting the farms. However, it was noted that under certain wind conditions, drifters were carried south into site MF-403. It also appears that, at certain phases of the tide, water from site MF-303 could be carried toward the farms in Seal Cove (to the west).

The data suggests that existing Bay Management Areas (BMAs) 20 and 21 should be considered as one BMA, but that within this area, site MF-303 is sufficiently isolated from the other sites, so that its status as the sole even year-class site in the area could be maintained. Sites in BMA 19 (White Head Island) were relatively isolated from the rest of southern Grand Manan.

The project succeeded in developing a better understanding of water circulation in the southern Grand Manan area and in establishing closer links between oceanographers and fish health specialists. In order to fully understand the links between oceanography and fish health, more knowledge is required on fish health factors, such as how long viruses can survive in seawater and movements of planktonic stages of sea lice.

RÉSUMÉ

Page, F.H., Chang, B.D., and Greenberg, D.A. 2004. Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: final project report. Can. Tech. Rep. Fish. Aquat. Sci. 2543: vi + 47 p.

Le projet sur l'océanographie et sur la santé des poissons a reçu des fonds dans le cadre du Programme coopératif de recherche-développement en aquaculture (PCRDA) du MPO à la fin de 2001. Le projet a porté principalement sur l'approfondissement des connaissances sur les voies de circulation et de transport de l'eau dans la région de la baie Long Pond, dans le sud de l'île Grand Manan, et sur l'application de ces connaissances à l'évaluation de l'influence des modes de circulation de l'eau sur la santé des poissons et la gestion de la baie. Les résultats sont résumés dans le présent rapport, qui contient aussi les présentations faites à la dernière réunion portant sur le projet, tenue le 17 février 2004.

Le projet comprenait la cueillette de données sur le terrain et l'élaboration d'un modèle de circulation de l'eau et de transport des particules. Des bouées dérivantes CAST (Convertible Accurate Surface Tracker) et des courantomètres InterOcean S4 et RDI Workhorse ADCP (Acoustic Doppler Current Profiling) ont été utilisés pour recueillir des données sur le terrain. Les résultats de ces travaux ont été comparés à ceux issus du modèle informatique, un modèle tridimensionnel aux éléments finis du sud de l'île de Grand Manan, d'une résolution de 50 à 100 m. Les courants dans ce modèle étaient dictés par la marée lunaire M_2.

En général, les données de terrain et les prédictions du modèle concordaient raisonnablement bien. Les écarts étaient facilement rationalisés. Par exemple, la plupart des passages du modèle n'incluaient pas l'effet du vent sur la circulation de l'eau malgré le fait qu'il avait parfois un effet sur la trajectoire des bouées dérivantes. Dans un secteur en particulier, des gens de l'endroit ont signalé l'existence d'une anomalie magnétique faussant les lectures du compas, ce qui aurait pu fausser aussi les lectures des courantomètres S4 prises à cet endroit. Des erreurs de précision mineures dans le trait de côte et la bathymétrie du modèle et les effets des pisciculture sur les courants (le modèle ne tenait pas compte de la présence de pisciculture quoique la présence de cages agit probablement sur la circulation de l'eau dans le voisinage des installations) peuvent avoir réduit la précision des comparaisons entre les courants observés et les courants modélisés dans quelques cas.

Un des principaux buts du projet était d'établir le niveau d'échange d'eau entre la seule ferme produisant des classes d'âge paires (MF-303, située dans le nord de la baie Long Pond) et la ferme la plus proche (MF-403, située à environ 2 km plein sud). Les résultats obtenus indiquent

que la circulation de l'eau attribuable aux marées dans le secteur de la ferme MF-303 se faisait en grande partie dans une direction est-ouest, soi[illegible]erpendiculairement à l'axe nord-sud reliant les fermes. On a toutefois noté que lorsque le vent venait d'une certaine direction, les bouées dérivaient vers le sud jusqu'à la ferme MF-403. Il semble en outre que de l'eau provenant de la ferme MF-303 pourrait être transportée à certains stades de la marée vers les fermes de l'anse Seal (située à l'ouest).

Les données recueillies donnent à penser que les zones de gestion des baies 20 et 21 devraient être considérées comme une zone unique, mais que, à l'intérieur de celle-ci, la ferme MF-303 est suffisamment isolée des autres pisciculture pour que son statut d'unique ferme produisant des classes d'âge paires dans la région soit maintenu. Les fermes situées dans la zone 19 (île White Head) se sont révélées relativement isolées du reste du secteur sud de l'île Grand Manan.

Le projet s'est révélé un succès pour ce qui est d'approfondir les connaissances de la circulation de l'eau dans le sud de l'île Grand Manan et d'établir des liens plus étroits entre les océanographes et les spécialistes de la santé des poissons. D'autres connaissances sur les facteurs agissant sur la santé des poissons, notamment le temps de survie des virus dans l'eau de mer et les déplacements des stades planctoniques du pou du poisson, sont requises afin de pouvoir comprendre pleinement les liens entre l'océanographie et la santé des poissons.

TABLE OF CONTENTS

Introduction and overview of the project rationale and objectives 1
Summary of the drifter component 3
Summary of the current meter component 4
Summary of the circulation modelling component 6
Summary of the fish health component 7
Summary of the particle tracking component 8
Overview of the project conclusions and influences to date 9
Overview of the project's knowledge transfers and impacts 11
Recommendations 12
References cited 14

Appendices

1. Agenda for the final project meeting 15
2. List of participants at the final project meeting 16
3. Introduction to the final project meeting 17
4. Drifter release experiments in southern Grand Manan 20
5. Current meter data 25
6. Modelling currents in Grand Manan shallows 29
7. Water circulation and management of ISA in the southwestern New Brunswick salmon aquaculture industry 36
8. Notes on the final project meeting's discussions and recommendations 43
9. List of project publications, reports, presentations, and meetings 45

INTRODUCTION AND OVERVIEW OF THE PROJECT RATIONALE AND OBJECTIVES

This report summarizes the results of the Aquaculture Collaborative Research and Development Program (ACRDP) Fish Health and Oceanography Project. These results were presented and discussed at the final meeting of the project team, held on 17 February 2004. This report includes an overview of the project's rationale and objectives, summaries of results for each of the project components, conclusions, and recommendations. The agenda, list of participants, and slides from the presentations at the final project meeting are included as appendices.

A brief overview of the project rationale and objectives is given below. Additional background can be found in Page and Chang (2002).

The design of the Fish Health and Oceanography Project began in the fall of 2000 and spring of 2001 and it initially received funding from the Fisheries and Oceans Canada (DFO) Aquaculture Collaborative Research and Development Program (ACRDP) in late 2001.

The consideration and approval of four new salmon farms in the southern Grand Manan area in 2001 triggered the desire for the project. One of the new sites raised the particular concern that an existing even year-class salmon farm (MF-303) in the Long Pond Bay area of southern Grand Manan would not be sufficiently isolated from the newly and conditionally approved odd year-class farm (MF-403) in terms of water exchange between the sites (Appendix 3, slide 3). There was also the more general concern within the fish health and salmon aquaculture communities that the Bay Management Area (BMA) boundaries in southern Grand Manan may not be consistent with water exchange patterns in the area and that the fish health management strategies for the area might be compromised (Appendix 3, slide 3). These concerns were combined with a research desire to improve our ability to link oceanography to fish health management issues.

The project team (Appendix 2) consisted of oceanographers and fish health specialists from DFO, biologists and fish health specialists from the New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA), representatives of the salmon industry (Northeast Salmon Inc., Heritage Salmon Ltd., Fundy Aquaculture Ltd., and the New Brunswick Salmon Growers' Association) and members of the regional Fish Health Technical Committee. The latter included provincial (NBDAFA), federal (DFO), university (Atlantic Veterinary College) and private (Aquaculture Veterinary Services International, Maritime Veterinary Services Ltd., Skretting) veterinarians and fish health specialists.

The conceptual approach adopted by the project was that of the passive advective transport and dispersal of viral particles that may be released from fish farms (Appendix 3, slide 4). Given the many uncertainties associated with the water-borne transmission of the infectious salmon anemia (ISA) virus, it was decided that it was reasonable for the project to assume the virus was passively transported in the upper few meters of the water column in association with buoyant organic matter shed by the caged salmon. Furthermore, it was decided that it was reasonable to focus on the mean tidally driven component of the circulation and its associated transport and dispersal properties. It was felt that although the tides are not constant and that other factors such

as wind influence the circulation, the most persistent component of the circulation was the tides and the mean tide was a good starting point. This enabled the project to develop a conceptual approach and useful information for immediate fish health management purposes, while generating a solid foundation that, in the future, could incorporate additional components such as wind-driven circulation and viral behaviour if deemed useful.

Although some hydrographic and current meter data had been previously collected in southern Grand Manan and a preliminary three-dimensional tidal circulation model had been developed, the work was not sufficiently advanced to adequately address the issues of concern. The preliminary model results (Appendix 3, slide 5) indicated the tidal circulation in the southern Grand Manan area was spatially complex, that the horizontal resolution of the model needed to be improved in some areas and that additional observations were needed to help calibrate and validate the model in the areas of interest. Hence, additional field work and model development was required and time was needed to develop, test and apply software tools to the questions and concerns that triggered the project.

The specific objectives of the project were therefore:

1. To develop a better understanding of the water circulation within the Long Pond Bay area of Grand Manan by:
   - obtaining empirical observations of drifter trajectories and current velocities in key areas,
   - analyzing existing and new observations, and
   - refining and calibrating a three-dimensional tidal circulation and particle tracking model.

2. To characterize the fish health issues of importance to the salmon aquaculture industry that may have a significant oceanographic component to their spread and management considerations, especially in the Long Pond Bay area.

3. To define approaches and guidelines for estimating fish health risks based on oceanographic information.

4. To examine the implications of water circulation in southern Grand Manan, and Long Pond Bay in particular, to the exchange of ISA between farms MF-303 and MF-403 and between BMAs 19, 20 and 21.

5. To facilitate the exchange of information between fish health specialists and oceanographers and hence help develop a mutually improved understanding of fish health and oceanographic issues in the Grand Manan area and help identify how oceanographic knowledge can contribute to the management of these issues.

6. Contribute to a general examination of the suitability of BMA boundaries in the southern Grand Manan area from the perspective of water circulation and exchange pathways, with particular attention given to the water exchanges between Seal Cove and Long Pond Bay and between Long Pond Bay and Duck Island Sound.

The next few sections of the report summarise the results from each project component, based on the presentations made at the final project meeting. These sections are followed by a summary of the key results and impacts of the project, along with a summary of the project conclusions, knowledge transfer activities, and recommendations.

SUMMARY OF THE DRIFTER COMPONENT

In order to obtain some empirical evidence and insight pertaining to the pathways and rates of movement and dispersal of materials drifting with the near surface (upper 1 m) portion of the water column, CAST (Convertible Accurate Surface Tracker) drifters were deployed at various locations and times (Appendix 4, slide 3). Each drifter consisted of a perforated sock barrel and an electronics package. The combination extended from the sea surface to a depth of 1 m. The electronics internally recorded the drifter's GPS (Global Positioning System) position at approximately 11-min intervals. The drifters were typically deployed in clusters of 3-4 drifters and tracked for about 6-24 h. The drifter positions were linearly interpolated to 15-min intervals (on the hour, quarter hour, half-hour and three-quarter hour). The dispersal of the drifters was estimated from the interpolated positions by calculating the time-dependent variance in the positions of the drifters relative to the cluster's centroid location (center-of-mass). The wind conditions during the drifter experiments were assumed to be those measured in nearby Cobscook Bay by the GOMOOS (Gulf of Maine Ocean Observing System) oceanographic and meteorological buoy.

The release locations, wind conditions, observed trajectories and temporal evolution of the estimated variances are shown in the figures included in Appendix 4. All of the experiments were conducted during time periods characterized by relatively weak winds (speeds <8 $m \cdot s^{-1}$). Several experiments were conducted when wind speeds were less than 5 $m \cdot s^{-1}$. This meant that most of the drifter tracks were only marginally affected by wind-driven currents and should be indicative of transport pathways generated by the tidal circulation.

Deployment #96 (Appendix 4, slide 4) occurred during 2-5 $m \cdot s^{-1}$ winds blowing from the northwest quadrant. The drifters moved from their release location near farm MF-303 toward the east and were recovered in an area with a high density of lobster traps, about 3 h after release. The pattern of dispersal initially followed the Okubo (1974) relationship but the rate of dispersal decreased as the drifters rounded the eastern corner of the farm site.

Deployment #97 (Appendix 4, slide 5) occurred during 4-5 $m \cdot s^{-1}$ winds blowing from the south. The drifters moved from their release locations west of farm MF-303 toward the east and were recovered about 2.5 h after their release. The pattern of dispersal followed the Okubo relationship throughout the deployment.

Deployment #98 (Appendix 4, slide 6) occurred during 2-6 $m \cdot s^{-1}$ winds blowing from the southwest quadrant of the compass. The drifters moved from their release locations west and south of farm MF-303 toward the east. Both clusters of drifters moved into the MF-303 farm site where they were recovered about 2 h after deployment. The pattern of dispersal followed the Okubo relationship throughout the deployment.

Deployment #99 (Appendix 4, slide 7) occurred during 4-8 $m \cdot s^{-1}$ winds blowing from the northwest quadrant of the compass. The drifters initially moved eastward from their release locations near or between farm sites MF-303 and MF-403. Soon thereafter they began to drift toward the south and southwest. The drifters released near site MF-303 approached site MF-403 after about 6 h of drifting, thus suggesting that moderate winds from the northwest can probably induce some water exchange between farm sites MF-303 and MF-403. The pattern of dispersal for the longest deployment generally followed the Okubo relationship throughout the deployment. One of the drifters remained in the water overnight and it drifted out of Long Pond Bay and returned on the following tide.

Deployment #100 (Appendix 4, slide 8) occurred during 1-5 $m \cdot s^{-1}$ winds blowing from the western quadrant of the compass. The drifter cluster (#100a) released in northern Seal Cove initially moved westward, then northward through two farm sites and then eastward into Long Pond Bay within about 16 h. This release experiment demonstrated that water from BMA 20 passes into BMA 21 and suggests that the boundary between these two BMAs is not indicative of an oceanographic separation. The drifters released near site MF-403 moved eastward from and drifted across Long Pond Bay. As in deployment #99 one of the drifters remained in the water overnight and it drifted out of Long Pond Bay. Unlike the drifter in release #99 it did not return to the bay on the following tide. The pattern of dispersal for the northern deployment generally followed the Okubo relationship although the temporal evolution of the variance seemed to be influenced by the passage of the drifters near the farm sites in northern Seal Cove.

Deployment #101 (Appendix 4, slide 9) occurred during 0-4 $m \cdot s^{-1}$ winds blowing mainly from the southern half of the compass. The drifters initially moved westward from their release locations and transited Long Pond Bay. As in deployments #99 and #100 two of the drifters remained in the water for more than a tidal cycle. Both drifted out of Long Pond Bay and did not return.

SUMMARY OF THE CURRENT METER COMPONENT

Current meter data was collected from about 20 locations within the southern Grand Manan area (Appendix 5, slide 2). InterOcean S4 current meters were deployed at several of the locations and RDI ADCP (Acoustic Doppler Current Profiler) instruments were deployed at a few locations to obtain time series of the vertical profile of the water velocity.

The main purpose of the current meter data was to provide a basis for calibrating and validating the circulation model. To this end, the time series from each of these instruments was plotted and processed through the Foreman (1978) tidal analysis package. These results are discussed in the next section in the context of a comparison with the current velocities predicted by the circulation model.

A secondary purpose of the current meter data was to provide an empirical estimate of the geographic extent and location of viral transport in the vicinity of the major fish farms of interest to this project. This extent was estimated by calculating the horizontal displacement vectors from the current meter data. The displacement over a tidal period (12.42 h) was estimated by initiating the cumulative displacement calculation every 15-30 min (the recording interval of the current

meters). The displacement trajectories were then plotted and the frequency histograms of the maximum displacement and displacement at the end of the 12.42-h period produced (Appendix 5, slides 4-8). Although this approach makes the erroneous assumption that the currents at the location of the current meter are representative of a larger spatial area (i.e. are spatially homogeneous), it gives an indication of what might be estimated in the absence of more detailed information such as that from circulation models.

The maximum displacements estimated from mooring #124 adjacent to farm site MF-403 ranged from 2 to about 8 km, with a visually estimated median of about 5 km (Appendix 5, slide 4). The net displacement after one tidal cycle ranged from 2-6 km, with a visually estimated median of 3-4 km. These displacements tended to be along a northeast to southwest axis. The magnitude of the displacements suggests the zone of influence of site MF-403 is throughout Long Pond Bay.

The maximum displacements estimated from mooring #141 located along the southern flank of farm site MF-303 ranged from 4 to about 12 km with a visually estimated median of about 6-8 km (Appendix 5, slide 5). The net displacement after one tidal cycle ranged from 4-10 km, with a visually estimated median of about 6 km. These displacements tended to be along an east to west axis and are suggestive of water exchange between MF-303 in northern Long Pond Bay and the sites in northern Seal Cove.

The maximum displacements estimated from mooring #126 located along the northern flank of farm site MF-303 ranged from <1 to >3 km, with a visually estimated median of about 2 km (Appendix 5, slide 6). The net displacement after one tidal cycle ranged from about 0.5 to >3 km, with a visually estimated median of about 2 km. These displacements tended to be in a northerly, easterly or westerly direction and are suggestive of relatively little water exchange between MF-303 in northern Long Pond Bay and any of the other sites in southern Grand Manan. The large difference in the displacement estimates derived from moorings #126 and #141 help illustrate the limited value of a single current meter mooring. The moorings were only a few hundred metres apart and the conclusions from one mooring were quite different from those of the other nearby mooring.

The maximum displacements estimated from mooring #147 adjacent to farm site MF-403 ranged from about 2-9 km, with a visually estimated median of about 6 km (Appendix 5, slide 7). The net displacement after one tidal cycle ranged from about 2-6 km, with a visually estimated median of 4 km. These displacements tended to be along an east-west axis. The magnitude of the displacements suggest the zone of influence of site MF-403 extends across Long Pond Bay but does not include the farm sites located to the north and south of the site. This is in contrast to the indication from the nearby mooring #124 that indicated an extensive exchange with the sites to the north and south of site MF-403. Hence, as with the moorings located near site MF-303, the moorings around site MF-403 showed evidence of considerable spatial variation.

The maximum displacements estimated from mooring #146 within northern Seal Cove ranged from about 3-13 km with a visually estimated median of about 8 km (Appendix 5, slide 8). The net displacement after one tidal cycle ranged from about 3-8 km, with a visually estimated median of 6 km. As with mooring #141 these displacements tended to be along an east-west axis

and an exchange of water between the farm sites in northern Seal Cove and northern Long Pond Bay.

In general the current meter data indicates that a 5-km radius circle does not accurately represent the tidal excursions in the southern Grand Manan area. In most cases, the shape of the tidal excursion, as measured by the current meters, is not circular, but is more likely to be elongated and the major axis of the displacement ellipse is often >5 km.

SUMMARY OF THE CIRCULATION MODELLING COMPONENT

The water circulation in the southern Grand Manan area was modelled using the QUODDY_DRY three-dimensional finite element circulation model (Greenberg et al., in press). The model was used to estimate the M_2 tidal circulation only. Wind, buoyancy and other tidally driven components of the flow were not estimated. The model uses 21 sigma levels in the vertical and models the tidal wetting and drying of inter-tidal areas. The horizontal resolution of the model varied geographically with low resolution (kilometres) in the Gulf of Maine and a few tens of metres in the inshore areas of southern Grand Manan (Appendix 6, slides 2-4). Although the geographic area of interest was southern Grand Manan, the geographical domain of the model was chosen to be the entire Bay of Fundy and Gulf of Maine area (Appendix 6, slide 2). This approach was chosen since it would have been difficult to parameterize and specify the boundary conditions around the island of Grand Manan.

The calibrated model produces estimates of the amplitudes and phases of the M_2 tidal elevation that agree well with those estimated from sea surface height data from several stations throughout the model domain (Appendix 6, slides 5-6). In the Appendix figure a difference between a model and observed estimate is indicated by a straight line connecting the observed amplitude and phase (indicated by a "+") with the corresponding model estimate (end of the straight line). In general the model amplitude was within a few centimeters of the observed and the phase was within about 1-2 degrees (~2-4 min in time).

Examples of the depth-averaged current estimated by the model are shown in Appendix 6, slides 7-9. The plot of the residual currents, the current averaged over a tidal cycle (12.42 h), indicates significant spatial variation in the residual flow, with weak residuals in the inshore areas of southern Grand Manan (Seal Cove, northern Long Pond Bay) and stronger residuals toward the south and east of these areas (Appendix 6, slide 7). The tidal currents during the peak in the flooding and ebbing of the tide and during high and low tide are also shown (Appendix 6, slides 8-9).

In an effort to further validate and fine-tune the model, current velocities predicted by the model at specific locations and depths were compared with those observed at corresponding locations (Appendix 6, slide 10). The model-predicted amplitude and phase was estimated from the model output at various depth levels (sigma co-ordinates) by an FFT approach. The amplitudes and phases of the various tidal constituents within the corresponding observed time series of water velocities were calculated using the Foreman (1978) tidal analyses and prediction package for the same depth levels (sigma levels). In the case of single point current meter records, such as those obtained by the S4 current meters, comparisons were made between the observed data and

model data from sigma-levels bracketing the depth of the current meter record. In the case of the data from the vertically profiling ADCP current meters, the comparison was accomplished by first interpolating the observed currents to the appropriate sigma levels and then analyzing the generated time series for sigma-level. Although all observational time series were analyzed for over 50 tidal constituents, only the amplitudes and phases of the M_2 tide (principal lunar) were considered for comparison to the output of the circulation model.

Comparisons between the observed and modelled currents were made graphically (Appendix 6, slides 11-12). In the slides, the solid lines of each ellipse represent the M_2 current estimated from the model output and the ellipse of dots represents the M_2 current estimated from the observations. The straight lines emanating from the ellipses represent the phases of the M_2 current estimates. A good agreement between the modelled and observed current is indicated by a close overlap of the dots and solid ellipses and the phase lines.

The comparisons between the observed and modelled currents (Appendix 6, slides 11-12) were generally good in both the amplitude and phase of the currents. However, in a few cases the agreement was not particularly good (e.g. Appendix 6, slide 12). These poor agreements may have been due to observational errors associated with localized magnetic anomalies (known by local fisherman to cause compass problems), inadequate representation of the local bathymetry or wind and wave effects on the measured currents.

A more detailed description of the circulation model is given in Greenberg et al. (in press).

SUMMARY OF THE FISH HEALTH COMPONENT

Although there are several fish diseases affecting caged salmon in the southern Grand Manan area, it was decided early on in the project that very little was known about the mechanisms governing the spread of these diseases from cage to cage and farm to farm. It was also agreed that it was probably reasonable to assume, at least at this point in time, that the work conducted in this project, although focused on the spread of ISA, would have general merit in the consideration of fish health management decisions associated with other diseases.

In the case of ISA it was decided that the project would approach the water-borne exchange of ISA virus particles between farm sites by assuming the virus particles were viable in seawater for one tidal cycle or 12.42 h (Page and Chang 2002). This was consistent with the assumptions made by workers in Scotland and Norway (Scottish Executive, Fisheries Research Services 2000; Norwegian Animal Health Authority 2002). It was also agreed that for the purposes of this project's modelling efforts, the virus particles shed by the fish or in blood water would be assumed to drift with the near surface water. This approach can be modified as additional information becomes available on the survival and behavior of the ISA virus (and other disease vectors) in seawater.

SUMMARY OF THE PARTICLE TRACKING COMPONENT

As mentioned in the project rationale and objectives, one of the main purposes for the above work was to examine the implications of water circulation in southern Grand Manan, and Long Pond Bay in particular, to the exchange of ISA between farms MF-303 and MF-403 and between bay management areas 19, 20 and 21. We implemented several approaches for estimating these exchanges, in part to illustrate the contrast between the approaches.

The simplest approach used for estimating the exchange of water or virus particles between sites was to make an estimate of the distance a viral or water particle might travel in one tidal cycle given a ball-park estimate of the magnitude of the typical tidal current in the area of interest. This distance was then used as the radius of a circle centered over each farm lease. Any farms within the chosen radius would then be identified as being potentially within the zone of influence of the central farm. The overlap in the circles would suggest an exchange of water between circles. This approach is inexpensive and quick to apply within a GIS (Geographic Information System). However, it does not take into consideration the complexities of the water circulation such as the directionality of water transport nor the spatial and temporal variation in transport patterns caused by the spatial and temporal variation in the currents. As a consequence, it may over- or underestimate the exchange between sites.

For application to the southern Grand Manan area, a distance of 5 km was chosen and circles of this radius were centered over each of the farms in southern Grand Manan (Appendix 7, slide 3). This distance was consistent with the strength of typical tidal currents in the area and was the distance identified in a Norwegian ISA management plan (Norwegian Animal Health Authority 2002) as being indicative of the distance of influence from an ISA-infected farm. The number of farms within each circle was tabulated and plotted in a histogram that identified each central farm and bay management area it was in (Appendix 7, slide 4). The number of overlaps between circles was also tabulated and plotted. The results indicated that the circles around each farm in BMA 20 and 21 contained 5-8 other farms and those in BMA 19 contained 2-3 other farms. The circles overlapped with 5-11 other circles. The circle around farm MF-403 encompassed 8 other farms including MF-303 and the circle around farm MF-303 encompassed 7 other farms including MF-403. These results obviously suggested that the farms and BMAs in southern Grand Manan were not independent, particularly those within BMAs 20 and 21. The farms within BMA 19 were suggested to be less connected with those in the other BMAs although there was considerable overlap in the circles. Only one of the three farms in BMA 19 had farms in another BMA within its circle.

As a contrast to the above simple approach, a more sophisticated approach was also used that took much of the spatial and temporal variation in the circulation into consideration. The approach implemented was to estimate the exchange of water, and by implication ISA virus, between the farm sites by calculating the transport pathways of particles with a particle tracking model based on the water circulation model described above. The particle transport model assumed the particles remained at 1 m below the sea surface and moved with the horizontal water velocities estimated by the circulation model for that depth. The transport pathways were estimated for each site by releasing at hourly intervals a grid of particles over the center of each site and tracking these particles for one tidal cycle each. These particle pathways or trajectories

were then plotted in a GIS and the polygon containing all of the particle positions calculated. This polygon was then used to estimate the exchange between sites in the same way as the circles described above.

As expected, the polygons produced by the model were not circular and they occupied much less geographic space than the simple circles (Appendix 7, slides 6-7). The polygons associated with each farm encompassed only one to three other farms in contrast to the five to eight encompassed by the circles (Appendix 7, slide 8). The polygon associated with farm MF-403 encompassed only one other farm (MF-408) and the polygon associated with farm MF-303 encompassed no other farms. The polygons associated with farms within BMAs 19 and 21 did not encompass farms from other BMAs whereas the polygons associated with two of the four BMA 20 farms encompassed one or two farms within the adjacent BMA 21.

The model approach also allows the relative frequency of exchange between farms to be estimated. As stated earlier, particles were released at hourly intervals. A plot of the trajectories of each of these releases indicates that the particle trajectories change over the tidal cycle (Appendix 7, slides 10 and 12). Hence, a farm falling within the polygon defined by the total number of releases may not fall within all of the polygons associated with each of the hourly releases. A suitable accounting of this dynamic could serve as an indication of the frequency or relative consistency of the exchange of water from one site to another.

The particle trajectories also give an indication of the temporal evolution of the radial distance traveled from the site of release (Appendix 7, slide 11). For example the particles released from farm MF-303 travel a maximum of about 3.5 km from the site in one tidal cycle and those released from farm MF-403 travel a maximum distance of about 6 km (Appendix 7, slide 13). These distances are somewhat consistent with the 5-km radius mentioned above.

An additional description of these particle-tracking results is contained in Page et al. (2004 in press).

OVERVIEW OF THE PROJECT CONCLUSIONS AND INFLUENCES TO DATE

The key results and conclusions of the project were presented and discussed at the final project meeting (Appendices 3-8). They included:

1. Empirical data on aspects of the oceanography of the Long Pond Bay and Seal Cove areas of southern Grand Manan. The acquired data included:
   - time series records of water velocities at several locations within the southern Grand Manan area (these results are described in Page et al. 2004, in press);.
   - trajectories of drifters released in the Seal Cove and Long Pond Bay areas (these results are described in Page et al. 2004, in press); and
   - vertical profiles of water temperature, salinity, density and dissolved oxygen at particular locations within Seal Cove and Long Pond Bay (these results are described in Page et al. 2004, in press).

2. A high spatial resolution and calibrated three-dimensional tidal circulation and particle transport model of the southern Grand Manan area.

3. Analyses and syntheses of data and model outputs that indicated:
   - the tidal exchange of water between salmon farm sites MF-303 and MF-403 is very limited on the time scale of a single tidal cycle (12.42 h);
   - tidal exchange exists between Seal Cove (BMA 20) and Long Pond Bay (BMA 19), particularly between farms 1) MF-202 and MF-292 in Seal Cove and MF-303 in Long Pond Bay 2) MF-270 and MF-491 in BMA 20 and MF-408 and MF-403 in BMA 19;
   - the tidal exchange between sites can be modified by a wind driven circulation and the combination can at times generate an exchange between the sites that is not produced by the tidal circulation alone; and
   - the tidal flow of water from three proposed sites in Duck Island Sound was into Bay Management Areas 19 and 21 with a particular preponderance to flow toward the salmon farm sites located along the southern and southwestern shore of White Head Island in BMA 19 (results not shown in this report).

4. A mutually enhanced level of understanding of the utility and complexity of fish health and oceanography interactions in terms of fish health management considerations by oceanographers and fish health specialists. For example participants are more aware that:
   - current measurements taken at any specific location are of limited value in assessing the exchange of water between sites;
   - drift excursions from farms in the southern Grand Manan area are in the range of several kilometers within a tidal cycle;
   - the exchange of water between farm sites varies with the phase of the tide and that the exchange patterns can be modified significantly by the presence of circulation driving forces such as wind;
   - simple considerations of the oceanography can be cost effective and useful but must be considered in the context that potentially important details are overlooked and hence management plans should take a risk assessment approach that the level of understanding into consideration;
   - the exchange of water between some farms in adjacent bay management areas is more prevalent than the exchange between some farms within a bay management area;
   - although the technology exists to measure and model some of the oceanographic details on relatively small spatial and temporal scales, this can often be time consuming and expensive and the biological aspects of fish health issues are usually not known at an equivalent level of detail and over a similar range of scales; and
   - Despite the limitations, the combination of empirical observation, modelling and visualization certainly contributes to enhancing the understanding of fish health management issues and is considered in the ongoing development of stronger and more effective fish health management practices and policies.

In addition to the above, the project team was asked at the final project meeting to consider what would happen if site MF-303 was shifted eastward? It was estimated that the exchange of water between site MF-303 and Seal Cove would probably be reduced and that the exchange with farm sites in the White Head Island area (BMA 19) might be increased. It was emphasized that this

estimate was based on no field data and no specific model runs. Subsequent to the meeting, the particle transport model was run assuming the location of site MF-303 was about 2 km eastward of its present position. The model output indicated the tidal exchange area associated with the new location would not enter BMA 20 (Seal Cove), but would overlap with two of the sites in BMA 19.

OVERVIEW OF THE PROJECT'S KNOWLEDGE TRANSFERS AND IMPACTS

KNOWLEDGE TRANSFER

The knowledge/technology developed as part of this project was transferred to project participants primarily through presentations and discussions at project workshops (listed below). In addition, much of the information was verbally and visually transferred to decision-makers and clients through many meetings and presentations as the information was requested and became available. These ranged from one-on-one meetings between project members and interested decision-makers or industry members to group meetings with regulators and industry. More formal presentations were made to conferences and workshops attended by interested members of the industry, regulatory agencies, academic institutions and interested others. Much of the work was published in technical reports that are distributed to 150 or more libraries around the world. Some of this material has been synthesised into primary publications that have been submitted. No doubt more of the material will be prepared for primary publication in the future as the material is further explored and it becomes relevant to other issues and scientific questions.

A list of the knowledge transfers are given in Appendix 9.

IMPACTS

The results, model outputs and understanding gained by the project had several significant impacts and benefits. These are summarized below.

1. Given the project focus, the primary impact of the project was perhaps the generation and contribution of its advice to the regulatory authorities and industry participants. The evidence and advice generated contributed to the decision to allow continuation of the salmon farming operations on site MF-403. As outlined previously, the primary motivation for the project was to generate advice concerning the exchange of water between salmon farm sites MF-403 and MF-303. This was of interest to the regulatory authorities, a condition of the initial salmon farming lease to MF-403, as well as of interest to other salmon growers in the southern Grand Manan area due to desires and concerns associated with the management of ISA in the area.

2. A second impact of the project was its contribution to the regulatory decisions concerning the approval of proposed sites MF-0419, MF-0418 and MF-0402. Although the water exchange patterns in the vicinity of these sites were not the primary focus of the project, the modelling results contributed to the decision to not approve these site applications.

3. A third impact of the project concerned the generation of advice dealing with the potential impact of salmon farming in Seal Cove on concentrations of dissolved oxygen in the area. Although the project was not designed for, nor focused on, addressing an issue of dissolved oxygen, the gathering of hydrographic data and the development of the circulation, transport and dispersal model provided some background data and capability for beginning to think about an approach to addressing the dissolved oxygen issue(s) in the area.

4. A benefit of the project was the further education of participants, regulatory authorities and other members of the salmon farming industry concerning the complexity of the water circulation patterns in the southern Grand Manan area. This impact will continue as the project results become more widely disseminated and considered, and decisions are made concerning the structure of Bay Management Areas in the southern Grand Manan area.

5. Another benefit concerns the increased awareness and enhanced appreciation of the contribution oceanography can make to the development and implementation of fish health management approaches in the southern New Brunswick area. This general awareness has percolated into NBDAFA's and industry's ongoing considerations for the sustainable development of salmon aquaculture in the southwestern New Brunswick area. As such, the approach is being applied to other geographic areas of southwestern New Brunswick. The work has also helped trigger the recognition that perhaps circulation dynamics can be incorporated into fish husbandry practices, such as harvesting operations, in an effort to help mitigate the exchange of water potentially carrying viral particles between farms.

6. A further benefit concerns the enhanced awareness and appreciation of the scientific participants towards the impact of this type of science on the development and regulation of the New Brunswick salmon industry. This awareness renews our belief, as project leaders, in the importance of conducting an ongoing range of complimentary scientific activities and discussing the strengths, weaknesses and assumptions associated with the results of these activities in the broader context of the applied issue before conclusions and advice are generated.

7. The work has been also been recognized nationally and internationally (USA, Faeroe Islands, Norway) as being useful and a state-of-the-art application of oceanography to the sustainable development of aquaculture.

RECOMMENDATIONS

At the final project meeting the project team made several recommendations for future work (Appendix 8). These are:

- Oceanography and estimates of water-mediated exchanges between sites and areas should continue to be considered in the development of fish health and husbandry management policies and practices and in the investigation of disease outbreaks.

    - *Although the effective dose for ISA is unknown, good information on the survival of the ISA virus in seawater is not yet available, the transmission of ISA may be mediated in*

part by non-physical mechanisms such as sea lice and improved bio-security appears to date to have greatly reduced the incidence of ISA in the southwestern New Brunswick area, the fish health specialists considered oceanographic information and knowledge to be generally useful.

- The use of one tidal excursion continues to be appropriate but the significance of other time scales and perturbations to this should be explored.

    - *The tidal excursion concept is more realistic than straight-line separation distances or circular buffer zones separating sites, and is worth the extra effort and expense. One tidal excursion is used in Norway and Scotland for ISA management.*

- Conduct similar work in other fish farming areas of southwest New Brunswick.

    - *It was acknowledged that efforts to apply the approach in the Cobscook Bay-Head Harbour-Western Passage area of southwestern New Brunswick and southeastern Maine and the Letete Passage area of southwestern New Brunswick are already underway.*

- Expand the oceanographic outputs from this approach by estimating how long it takes for particles to leave a site (i.e. a site specific residence times), residence times of bays and the percentage of particles that originate from a specific site that travel to another specific site or area.

- The oceanographic approach should be considered in epidemiological approaches.

    - *This closer linkage is being pursued with staff of the USDA in examining the spread of ISA in the Cobscook Bay-Head Harbour-Western Passage area of southwestern New Brunswick and southeastern Maine.*

- Examine the potential for oceanographic processes to explain some of the historical disease outbreaks in the southwestern New Brunswick area. For example, try to address why some isolated salmon farm sites became infected with ISA.

- Conduct investigations on links between oceanography and sea lice dispersal.

- Based on the project results and the philosophy of a tidal excursion based fish health policy, it is recommended that Bay Management Areas (BMAs) 20 and 21 be combined and that BMA 19 could remain a separate BMA. It is also acknowledged that site MF-303 is somewhat separated from other sites in BMAs 20 and 21 and that its status as the only even year-class site within the southern Grand Manan area may constitute an acceptable risk at this time.

ACKNOWLEDGEMENTS

This project was funded in part by the DFO Aquaculture Collaborative Research and Development Program (ACRDP), Heritage Salmon Ltd., and the New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA). The work was conducted in collaboration with the New Brunswick Salmon Growers' Association (NBSGA), Heritage Salmon Ltd., Northeast Salmon Inc., and Fundy Aquaculture Ltd. We also wish to acknowledge the input provided by M. Beattie and S. McGeachy (NBDAFA), G. Olivier (DFO), N. Halse (NBSGA), and the Fish Health Technical Committee.

References cited

Foreman, M.G.G. 1978. Manual for tidal currents analysis and prediction. Pac. Mar. Sci. Rep. 78-6: 57 p.

Greenberg, D.A., Shore, J.A., Page, F.H., and Dowd, M. 2004. Modelling embayments with drying intertidal areas for application to the Quoddy region of the Bay of Fundy. Ocean Model. (accepted for publication).

Norwegian Animal Health Authority (Statens Dyrehelsetilsyn). 2002. Contingency plan for control of Infectious Salmon Anaemia (ISA) in Norway. Norwegian Animal Health Authority, Oslo, Norway. (Available at: http://dyrehelsetilsynet.mattilsynet.no/english/)

Okubo, A. 1974. Some speculations on oceanic diffusion diagrams. Rapp. Proc. Verb. Cons. Int. Explor. Mer., 167: 77-85

Page, F.H., and Chang, B.D. (Editors.). 2002. Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: Report of the initial project meeting, 18 December 2001, Can. Tech. Rep. Fish. Aquat. Sci. 2409: vii + 48 p.

Page, F.H., Chang, B.D., Losier, R., Greenberg, D., and McCurdy, P. 2004. Water circulation and management of ISA in the southwest New Brunswick salmon aquaculture industry. Aquacult. Assoc. Can. Spec. Publ. 8: 64-68 (in press).

Scottish Executive, Fisheries Research Services. 2000. Final Report of the Joint Government/Industry Working Group on Infectious Salmon Anaemia (ISA) in Scotland. Scottish Executive, Fisheries Research Services, Marine Laboratory, Aberdeen, Scotland.

Appendix 1: Agenda for the final project meeting

Date and Time: 17 February 2004, 10:00 a.m. - 4:00 p.m.
Location: Fisheries and Oceans Canada, Biological Station, Conference Centre,
531 Brandy Cove Road, St. Andrews, New Brunswick

10:00 a.m. Introductions and announcements

10:15 a.m. Brief review of the project objectives (F. Page)

10:30 a.m. Overviews of Oceanographic Work conducted as part of the project
- Drifter experiments (F. Page)
- Current meter deployments (F. Page)
- Circulation modelling (D. Greenberg)

12:00 – 12:30 LUNCH (provided)

12:30 p.m. Project findings in relation to the fish health objectives (F. Page)

13:00 p.m. Discussion and identification of conclusions
- Exchange between farm sites
- Exchange between BMAs
- Guidelines concerning the types of oceanographic information; its presentation and interpretation that are best suited to the fish health community.

14:30 p.m. Discussion and identification of the usefulness of this type work in SWNB as a whole

15:00 p.m. Wrap-up issues
- Reports
- Thoughts on presenting results to a broader portion of the industry

16:00 p.m. Adjournment

For further information contact:

Fred Page: 506-529-5935 (pagef@mar.dfo-mpo.gc.ca)
Blythe Chang: 506-529-5907 (changb@mar.dfo-mpo.gc.ca)

Appendix 2: List of participants at the final project meeting

17 February 2004
Conference Centre, St Andrews Biological Station

Name	*Affiliation*
Steve Backman	Skretting (St. Andrews)
Blythe Chang	Fisheries and Oceans Canada (St Andrews Biological Station)
Jason Chaffey	Fisheries and Oceans Canada (Bedford Institute of Oceanography)
Pat Fitzgerald	Heritage Salmon Ltd. (Blacks Harbour)
Dave Greenberg	Fisheries and Oceans Canada (Bedford Institute of Oceanography)
Barry Hill	New Brunswick Department of Agriculture, Fisheries & Aquaculture (St. George)
Rupert Lambert	Northeast Salmon Inc. (Grand Manan)
John L'Aventure	Fundy Aquaculture Ltd. (Grand Manan)
Randy Losier	Fisheries and Oceans Canada (St Andrews Biological Station)
Sandi McGeachy	New Brunswick Department of Agriculture, Fisheries & Aquaculture (Fredericton)
John O'Halloran	Aquaculture Veterinary Services International (Old Ridge, NB)
Fred Page	Fisheries and Oceans Canada (St Andrews Biological Station)
Project participants unable to attend this meeting	
Mike Beattie	New Brunswick Department of Agriculture, Fisheries & Aquaculture (St. George)
Nell Halse	New Brunswick Salmon Growers' Association (Letang, NB)
Larry Hammell	Atlantic Veterinary College (Charlottetown)
Dan MacPhee	Maritime Veterinary Services Ltd. (St. George)
Gilles Olivier	Fisheries and Oceans Canada (Moncton)
Bill Robertson	Heritage Salmon Ltd. (Blacks Harbour)
Darcy Russell	Northeast Salmon Inc. (Grand Manan)
Jamey Smith	AMEC Earth & Environmental (Fredericton)

Appendix 3: Introduction to the final project meeting
(17 February 2004, presented by F. Page)

Slide 1

Introduction

Purpose of Meeting

- To remind us of project objectives
- To briefly present the major project findings
- To identify and discuss project conclusions

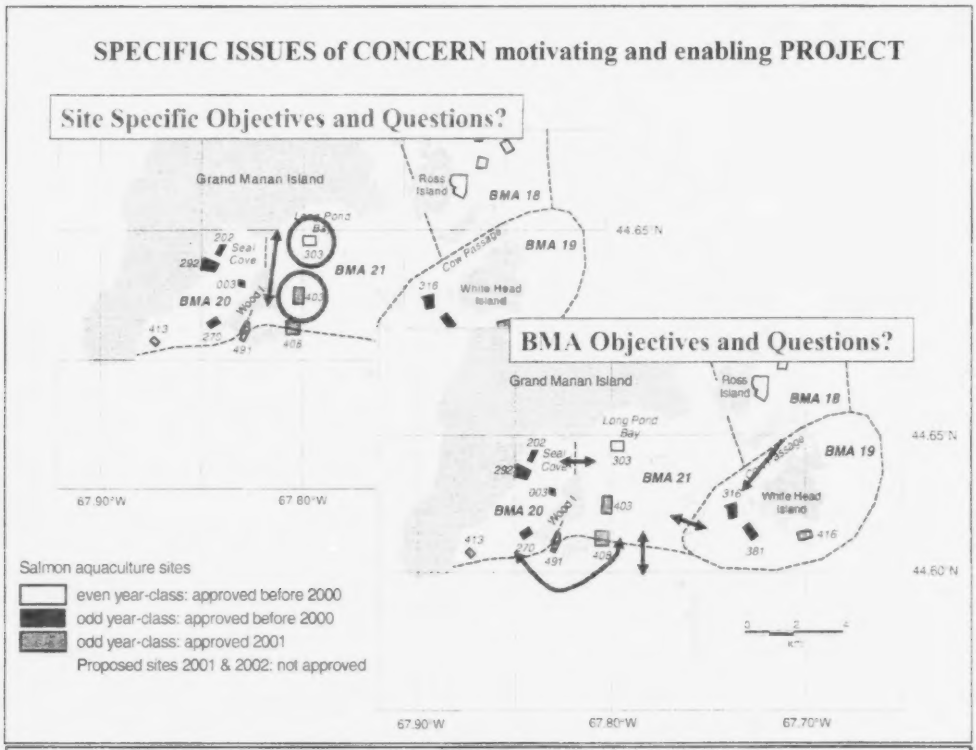
Slide 2

Project Background and Rationale

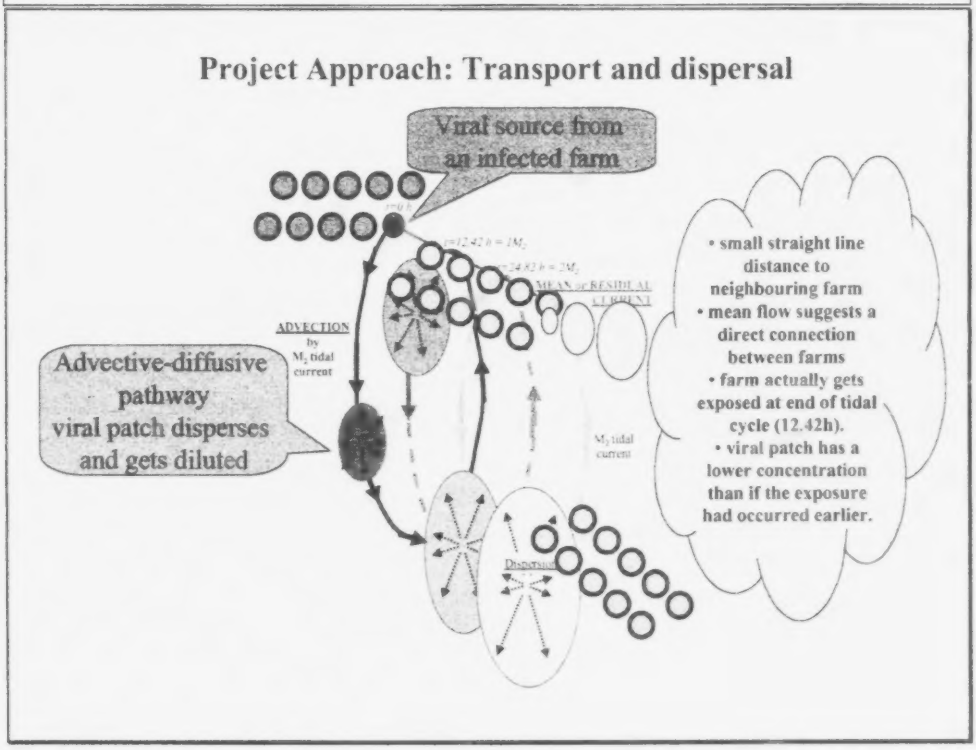
- The concept for this project began in the fall of 2000 and spring of 2001.
- It was generated by a combination of several motivations
  - the review process for the 2000-2001 aquaculture site applications raised concerns that the new salmon farms being proposed for Long Pond Bay and adjacent areas of Grand Manan might impact the operation of existing farms within the area with respect to the year-class separation and fish health management goals in general.
  - the recognition that the boundaries of the bay management areas in the southern Grand Manan might not adequately reflect the pattern of water circulation and exchange and that the existing boundaries may not be the best for achieving the goals of bay management practice.
  - the existing level of understanding with respect to the water circulation was inadequate to address these concerns.
  - A desire to try and establish a closer link between oceanographers and fish health specialists and to draft some general guidelines concerning the types of oceanographic information, its presentation and interpretation that best suited the fish health community.

Appendix 3: Introduction to the final project meeting
(17 February 2004, presented by F. Page)

Slide 3



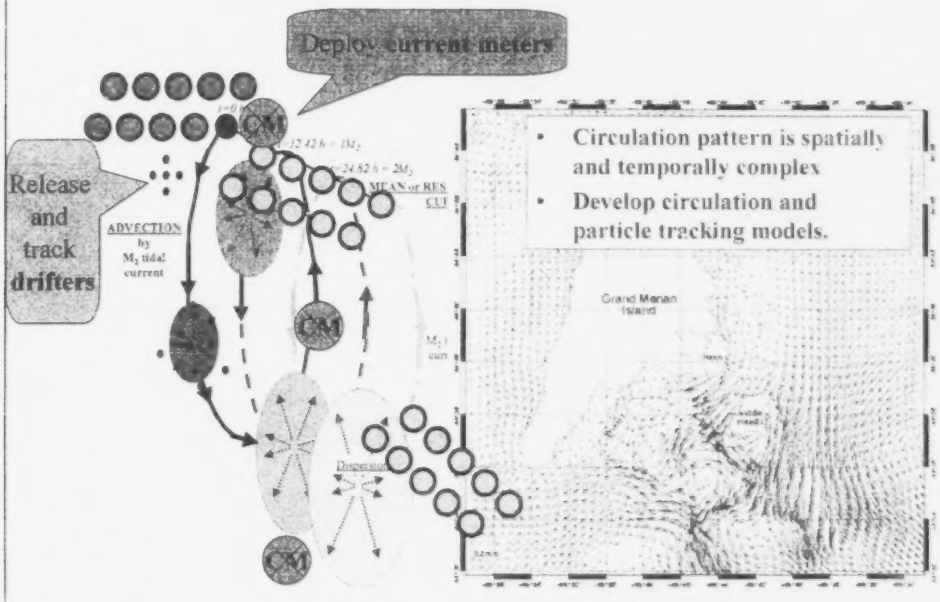
Slide 4


Project Approach: Transport and dispersal
Viral source from an infected farm
ADVECTION by M2 tidal current
Advective-diffusive pathway viral patch disperses and gets diluted
M2 tidal current
Dispersion
• small straight line distance to neighbouring farm
• mean flow suggests a direct connection between farms
• farm actually gets exposed at end of tidal cycle (12.42h).
• viral patch has a lower concentration than if the exposure had occurred earlier.

Appendix 3: Introduction to the final project meeting
(17 February 2004, presented by F. Page)

Slide 5

Project Approach: Measure and model



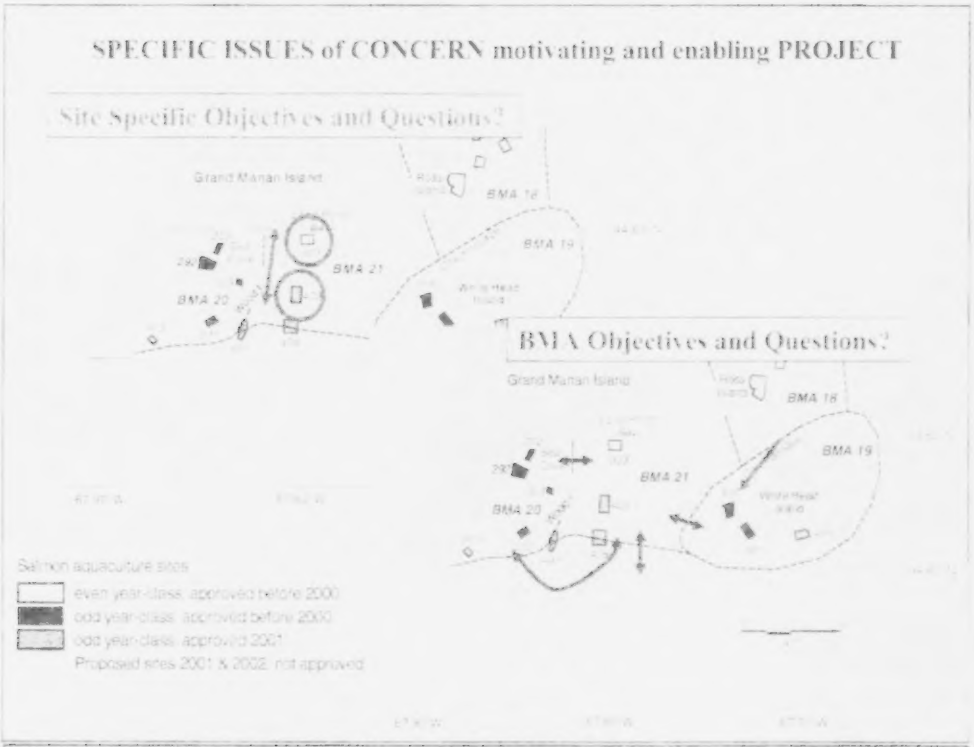
Slide 6

Project Objectives

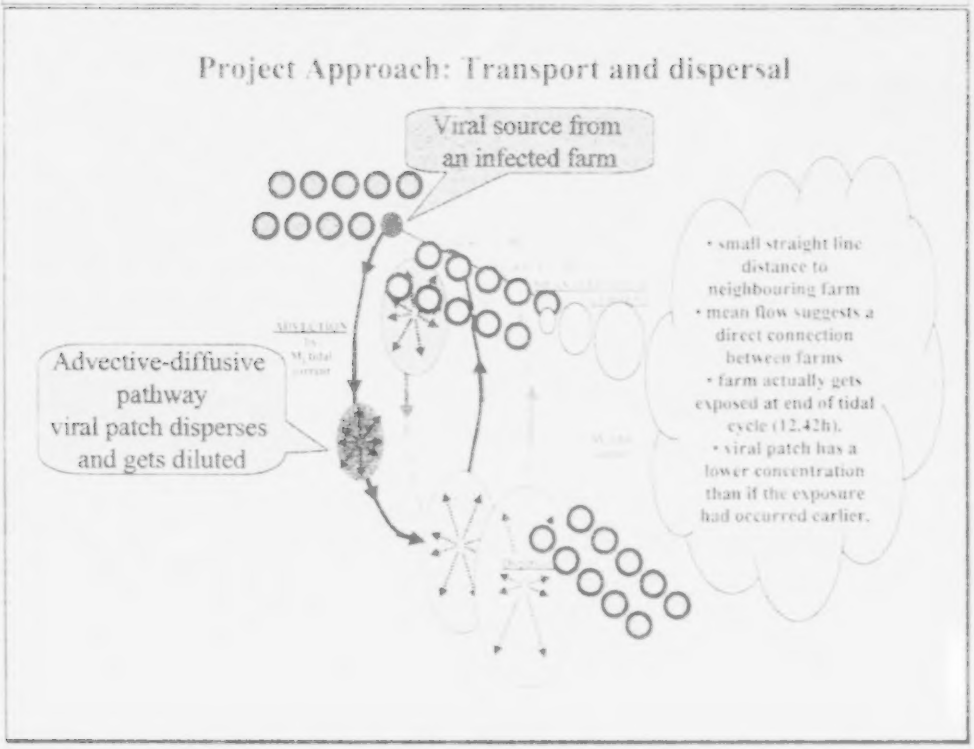
- To develop a better understanding of the water circulation within the Long Pond Bay area of Grand Manan by:
  - obtaining more observations, especially in key areas;
  - more fully analyzing existing and new observations; and
  - by refining a three-dimensional tidal circulation model.
- To characterize the fish health issues of importance to the salmon aquaculture industry that may have a significant oceanographic component to their spread and management considerations, especially in the Long Pond Bay area and to define approaches and guidelines for estimating fish health risks based on oceanographic information.
- To re-examine the implications of the water circulation in Long Pond Bay to the fish health and BMA boundaries within the area.

Appendix 3: Introduction to the final project meeting
(17 February 2004, presented by F. Page)

Slide 3


SPECIFIC ISSUES of CONCERN motivating and enabling PROJECT
Site Specific Objectives and Questions?
Grand Manan Island
BMA 18
BMA 19
BMA 21
BMA 20
BMA Objectives and Questions?
Salmon aquaculture sites
even year-class: approved before 2000
odd year-class: approved before 2000
odd year-class: approved 2001
Proposed sites 2001 & 2002: not approved

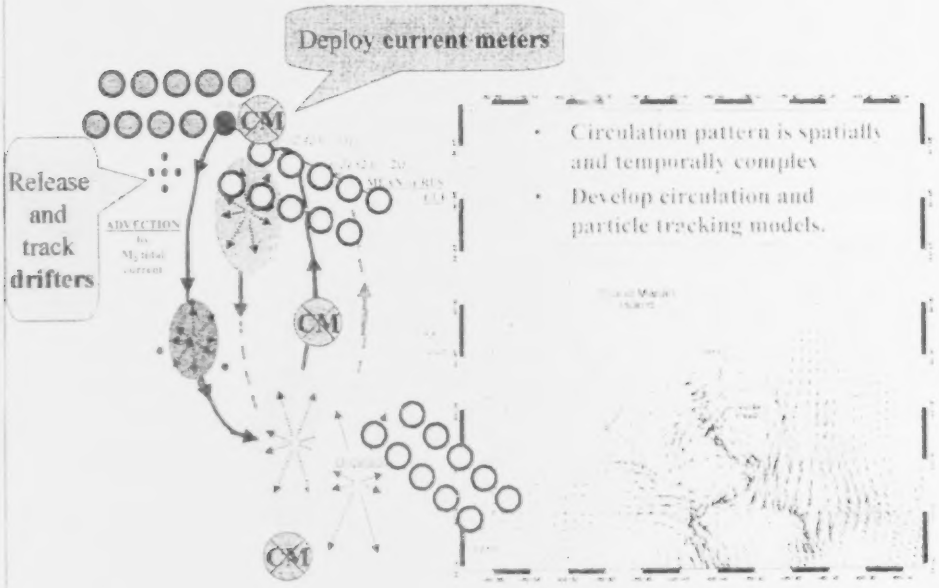
Slide 4


Project Approach: Transport and dispersal
Viral source from an infected farm
Advective-diffusive pathway viral patch disperses and gets diluted
• small straight line distance to neighbouring farm
• mean flow suggests a direct connection between farms
• farm actually gets exposed at end of tidal cycle (12.42h).
• viral patch has a lower concentration than if the exposure had occurred earlier.

Appendix 3: Introduction to the final project meeting
(17 February 2004, presented by F. Page)

Slide 5

Project Approach: Measure and model



Slide 6

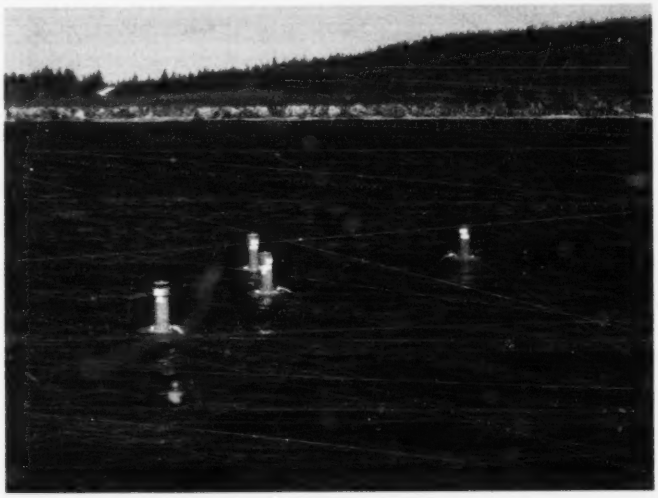
Project Objectives

- To develop a better understanding of the water circulation within the Long Pond Bay area of Grand Manan by:
  - obtaining more observations, especially in key areas;
  - more fully analyzing existing and new observations; and
  - by refining a three-dimensional tidal circulation model.
- To characterize the fish health issues of importance to the salmon aquaculture industry that may have a significant oceanographic component to their spread and management considerations, especially in the Long Pond Bay area and to define approaches and guidelines for estimating fish health risks based on oceanographic information.
- To re-examine the implications of the water circulation in Long Pond Bay to the fish health and BMA boundaries within the area.

Appendix 4: Drifter release experiments in southern Grand Manan
(17 February 2004, presented by F. Page)

Slide 1

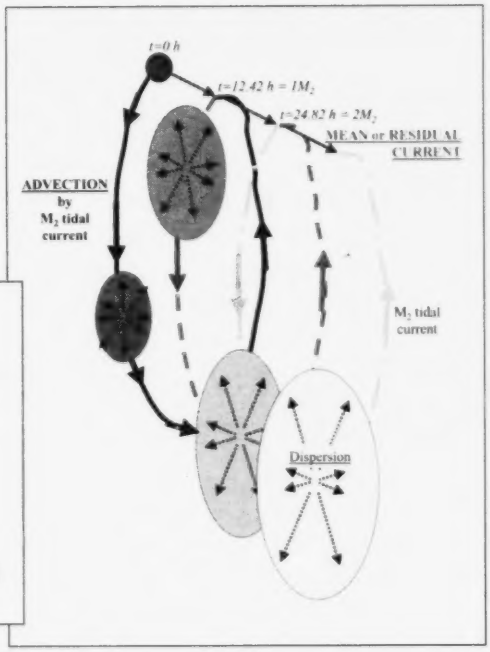
Drifter Release Experiments in southern Grand Manan



Randy Losier
Paul McCurdy
Fred Page

Slide 2

Drifter Release Experiments in southern Grand Manan



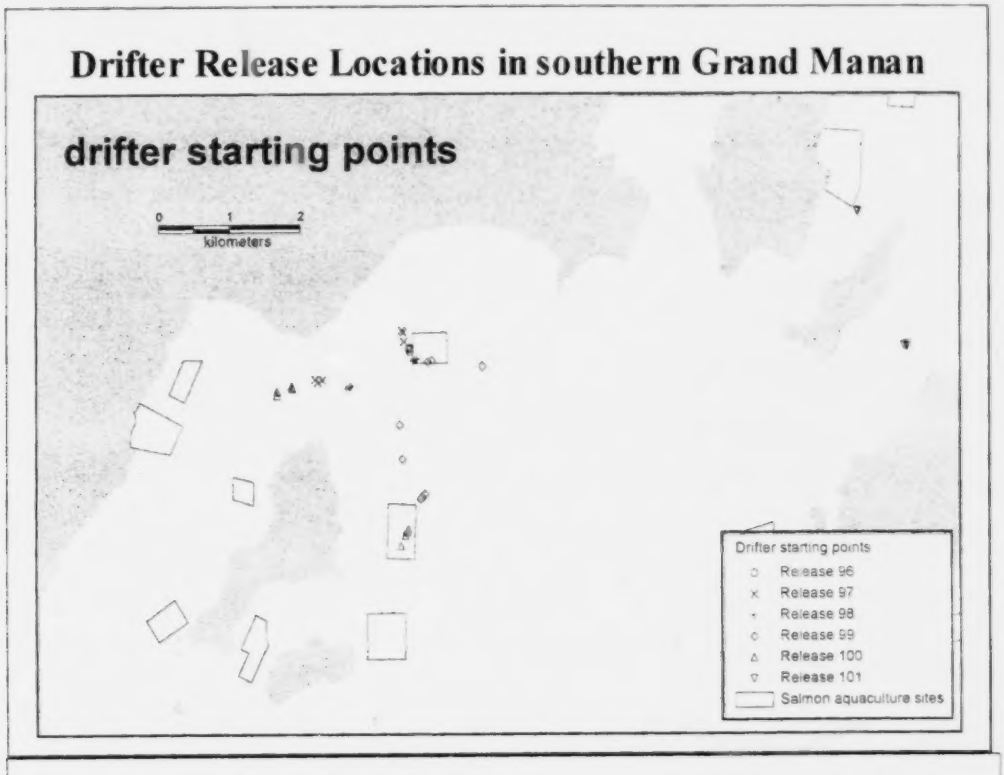
Okubo based Dilution Factor

hr after rel.	L=20m	L=200m
1.0	10x	2x
6.21	600x	23x
12.42	1500x	100x

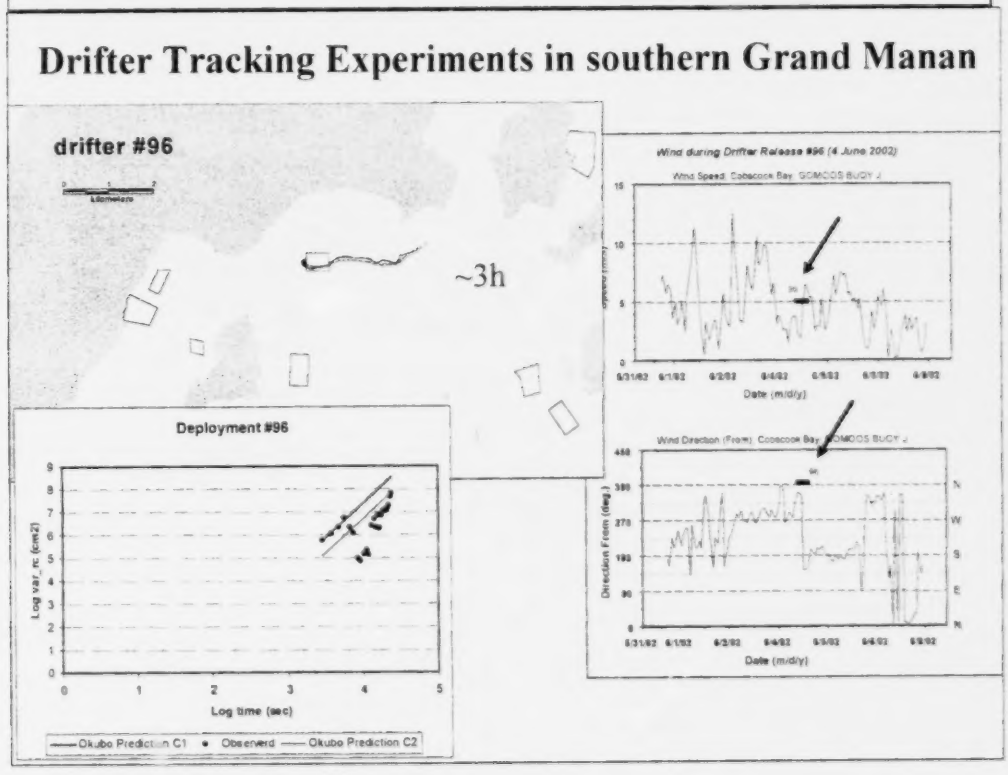
L = measure of scale (length) of patch
(dilution rate is scale dependent)

Appendix 4: Drifter release experiments in southern Grand Manan
(17 February 2004, presented by F. Page)

Slide 3

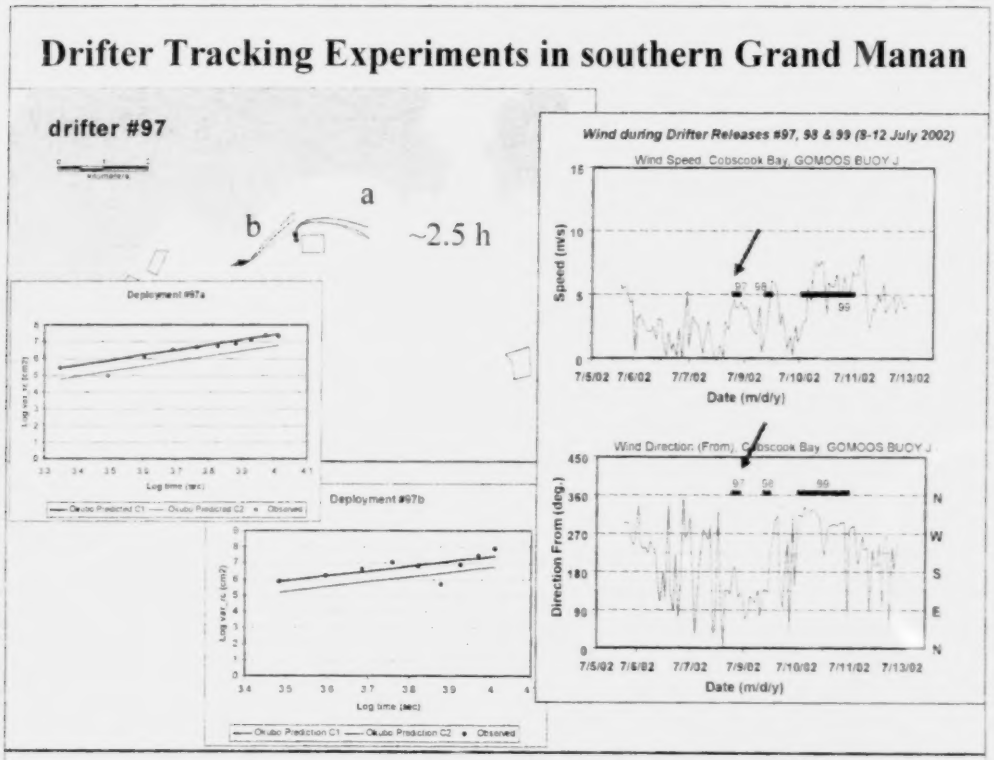


Slide 4

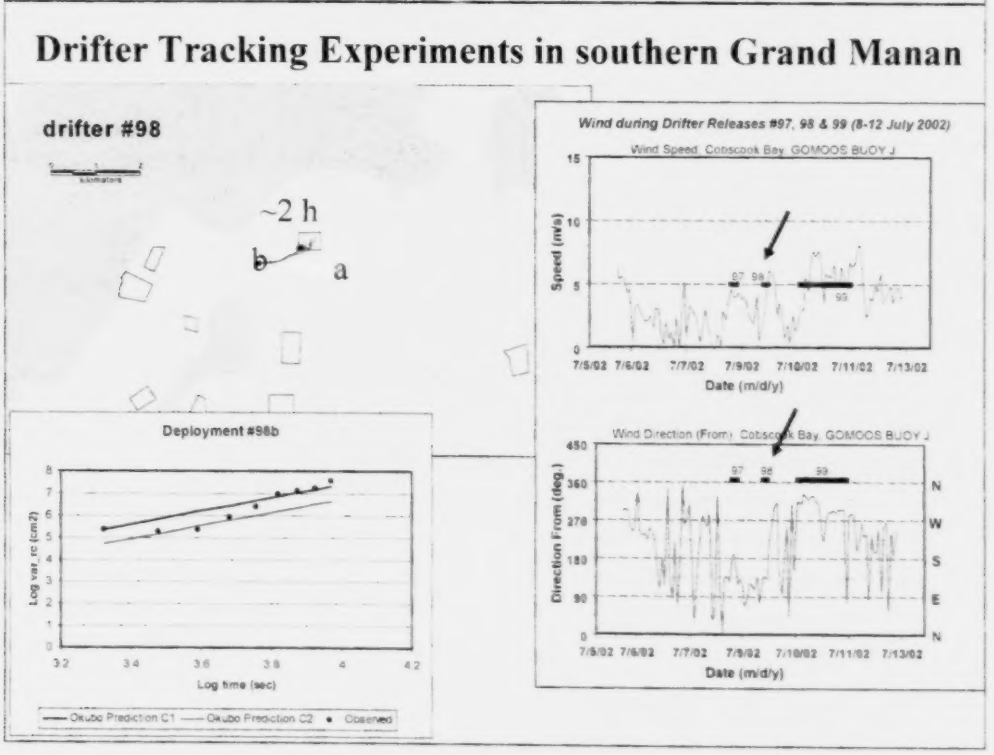


Appendix 4: Drifter release experiments in southern Grand Manan
(17 February 2004, presented by F. Page)

Slide 5

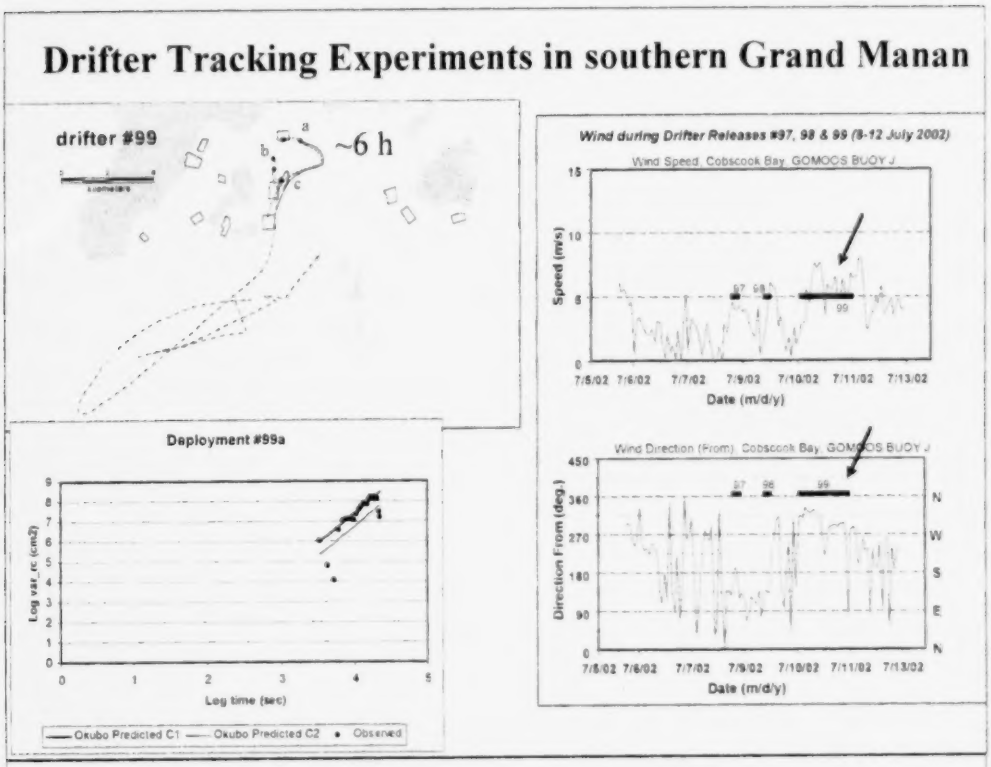


Slide 6

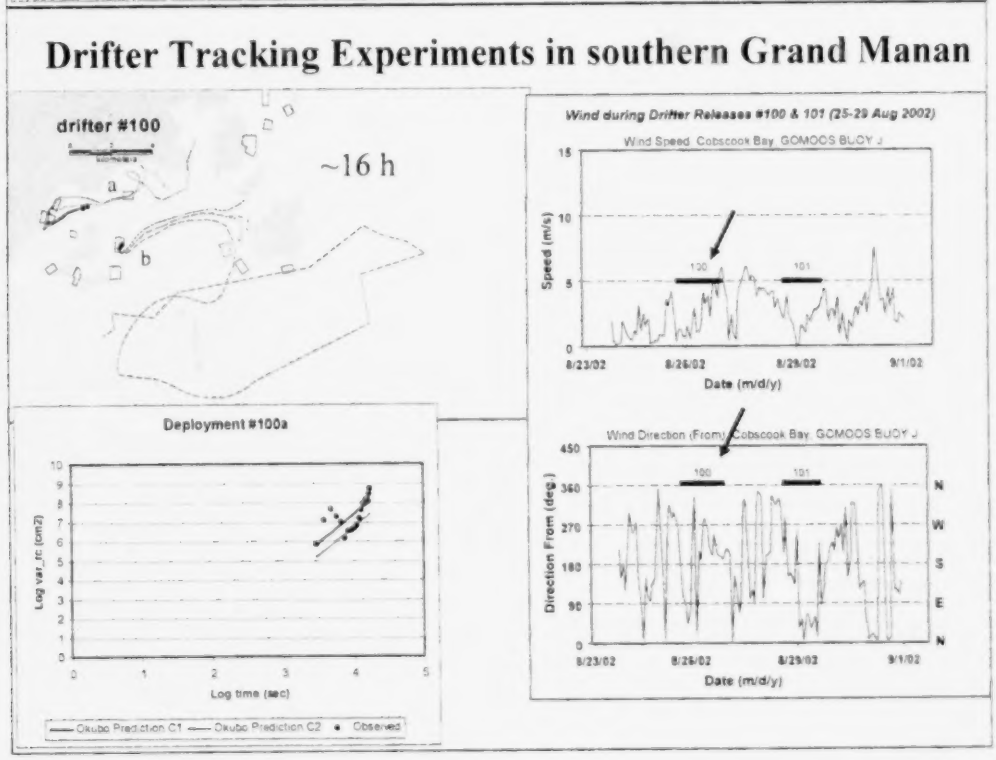


Appendix 4: Drifter release experiments in southern Grand Manan
(17 February 2004, presented by F. Page)

Slide 7



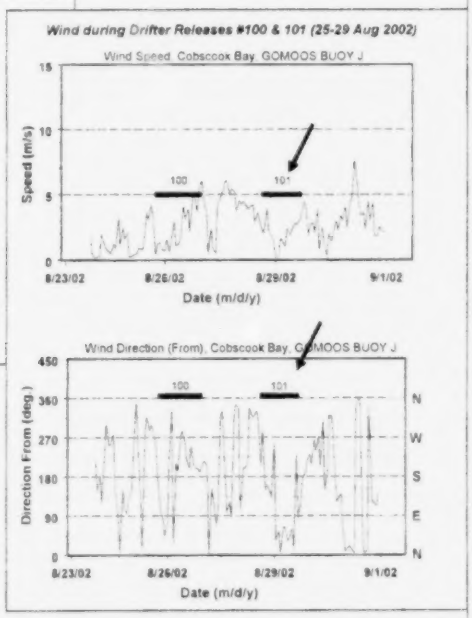
Slide 8



Appendix 4: Drifter release experiments in southern Grand Manan
(17 February 2004, presented by F. Page)

Slide 9

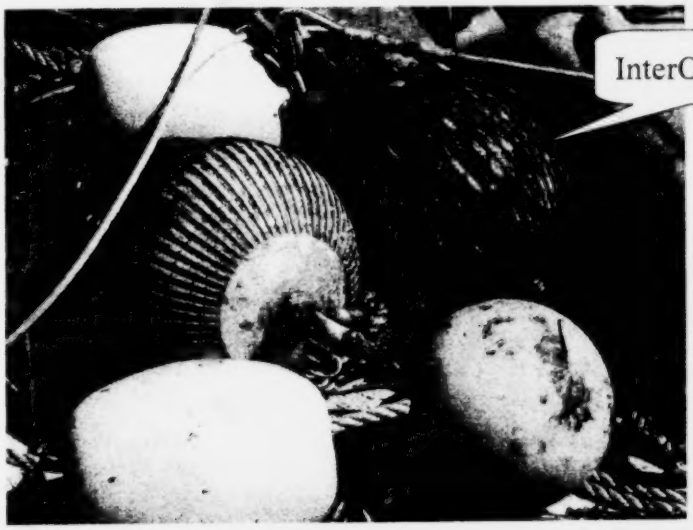
Drifter Tracking Experiments in southern Grand Manan



Appendix 5: Current meter data
(17 February 2004, presented by F. Page)

Slide 1

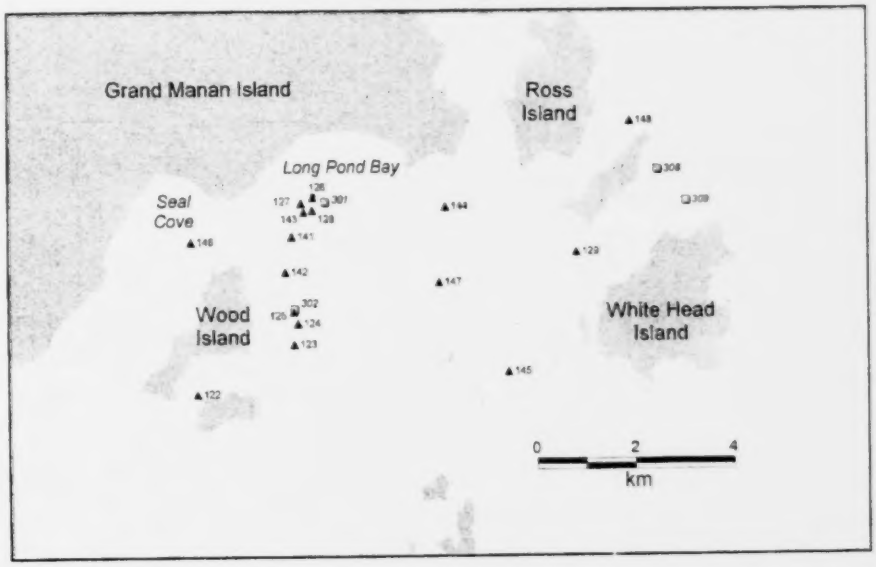
Current Meter Data



Randy Losier
Paul McCurdy
Fred Page
Dave Greenberg

Slide 2

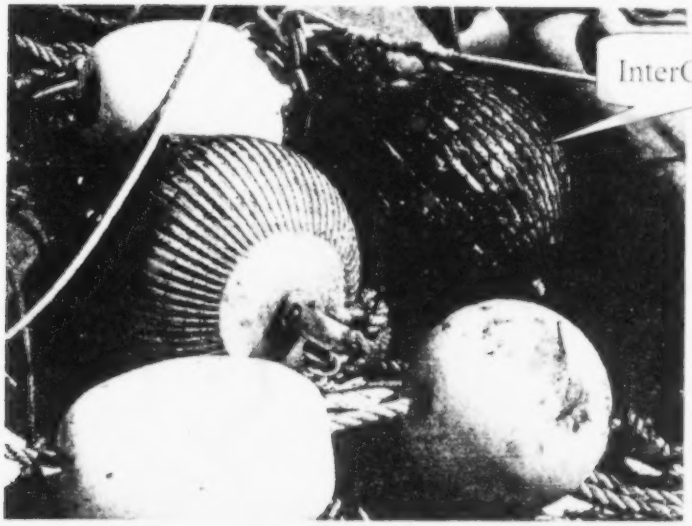
Southern Grand Manan Current Meter (CM) moorings



Appendix 5: Current meter data
(17 February 2004, presented by F. Page)

Slide 1

Current Meter Data



Randy Losier
Paul McCurdy
Fred Page
Dave Greenberg

Slide 2

Southern Grand Manan Current Meter (CM) moorings

Appendix 5: Current meter data
(17 February 2004, presented by F. Page)

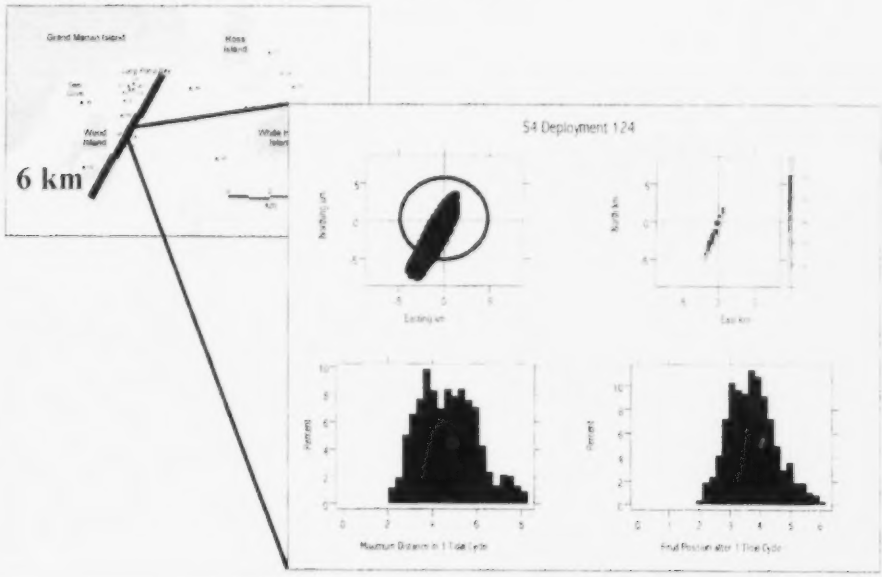
Slide 3

Current Meter Analyses

- Time series plots of data - handouts
- Tidal analyses - some results shown in current model presentation
- Tidal excursion calculations

Slide 4

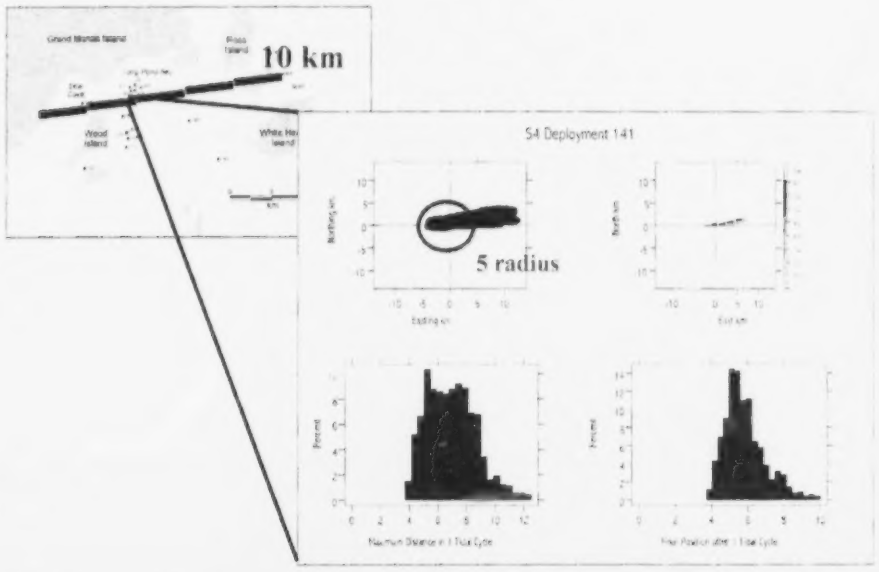
Southern Grand Manan CM mooring #124 near MF-403



Appendix 5: Current meter data
(17 February 2004, presented by F. Page)

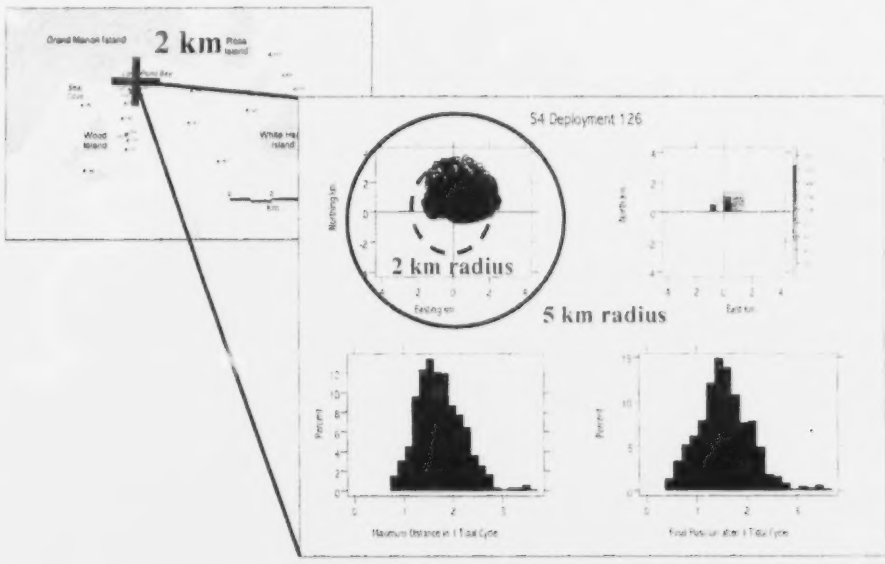
Slide 5

Southern Grand Manan CM mooring #141 south of MF-303



Slide 6

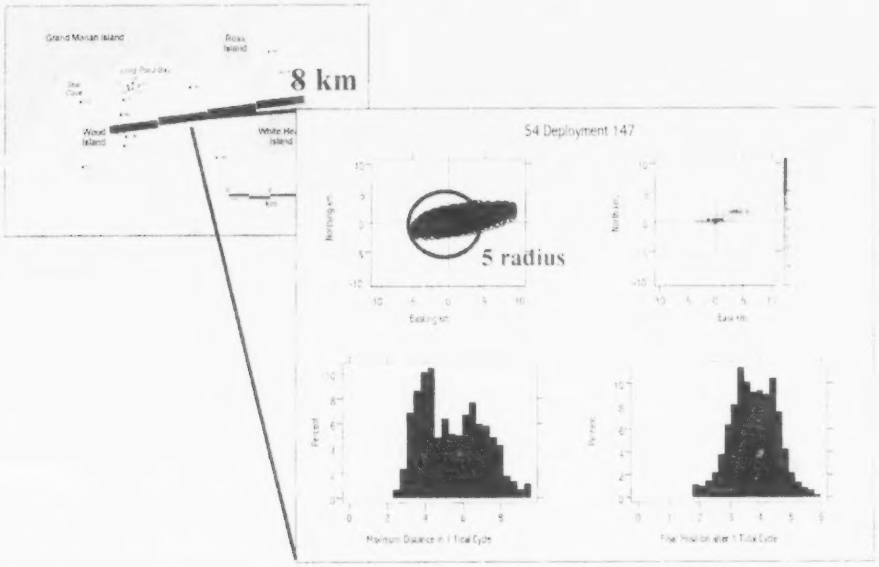
Southern Grand Manan CM mooring #126 near MF-303



Appendix 5: Current meter data
(17 February 2004, presented by F. Page)

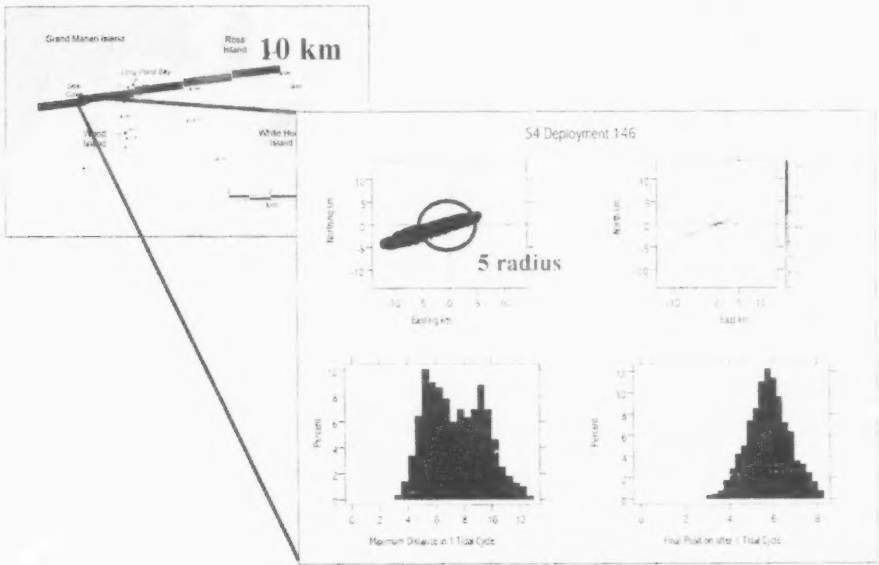
Slide 7

Southern Grand Manan CM mooring #147



Slide 8

Southern Grand Manan CM mooring #146
Seal Cove - Long Pond Bay channel



Appendix 6: Modelling currents in Grand Manan shallows
(17 February 2004, presented by D. Greenberg)

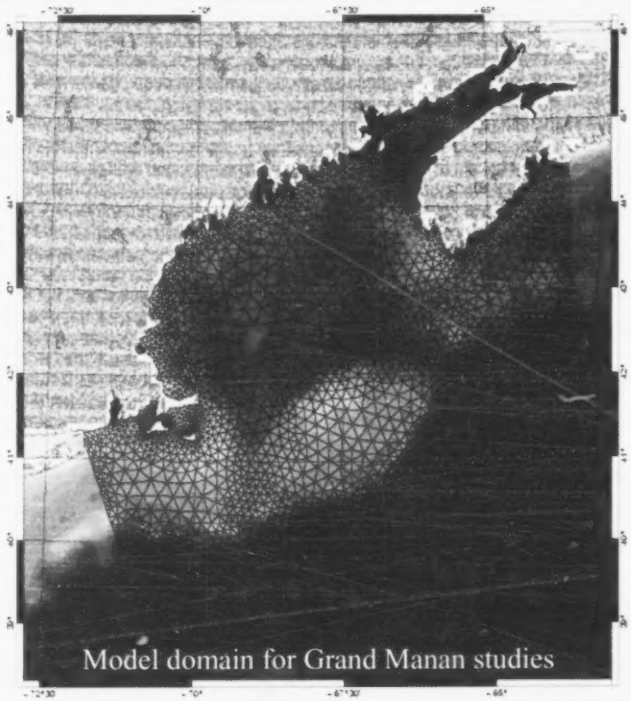
Slide 1

Modelling Currents in Grand Manan Shallows

David Greenberg, Jason Chaffey
Bedford Institute of Oceanography

Fred Page, Randy Losier
St. Andrews Biological Station

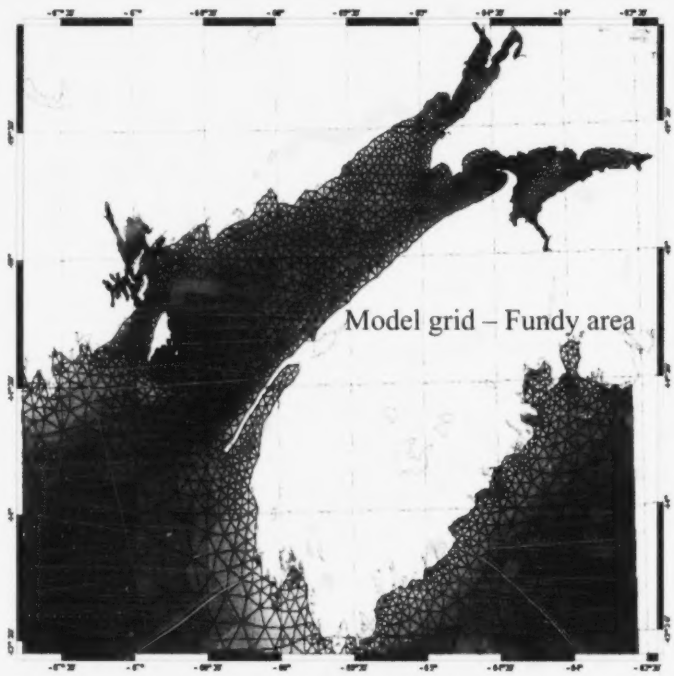
Slide 2



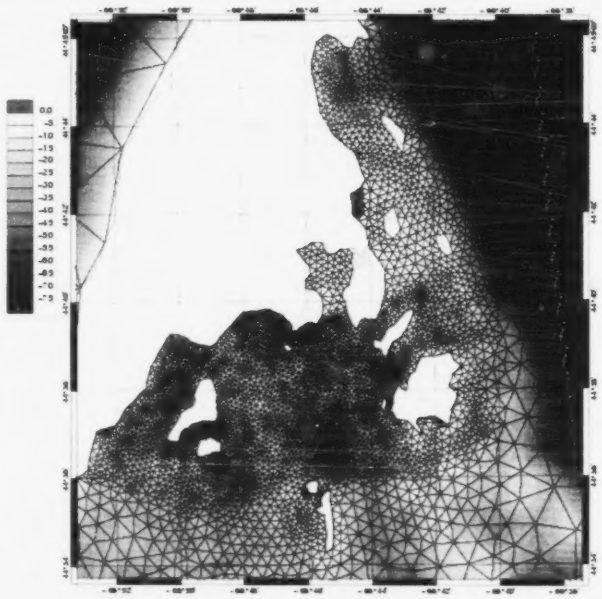
Model domain for Grand Manan studies

Appendix 6: Modelling currents in Grand Manan shallows
(17 February 2004, presented by D. Greenberg)

Slide 3



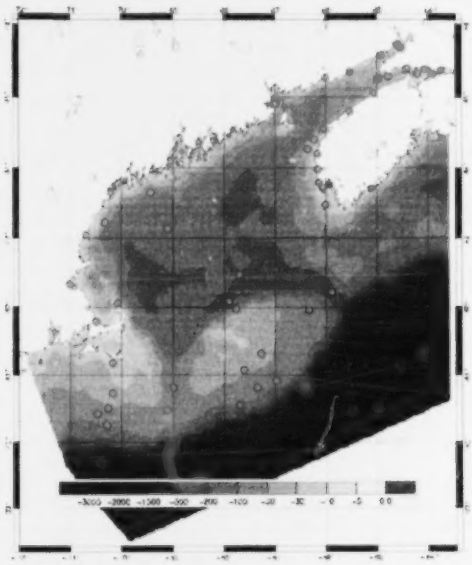
Slide 4



Detail of model - east Grand Manan shallows

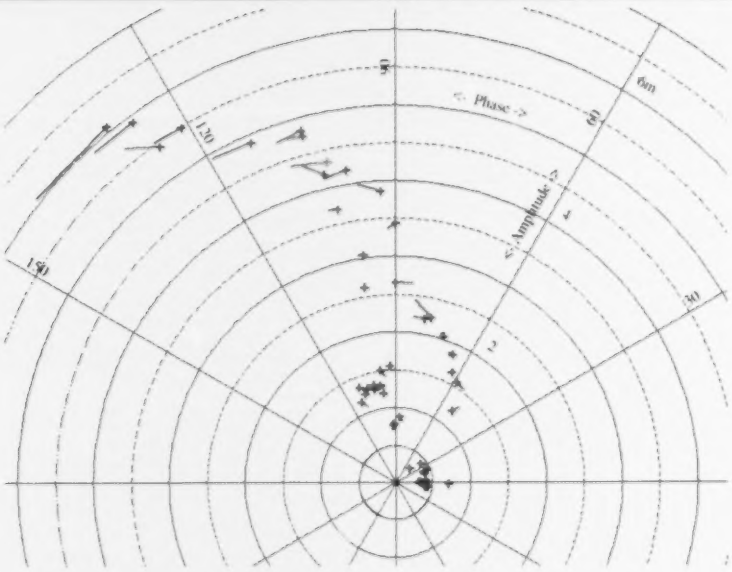
Appendix 6: Modelling currents in Grand Manan shallows
(17 February 2004, presented by D. Greenberg)

Slide 5



Tide stations for comparison with models

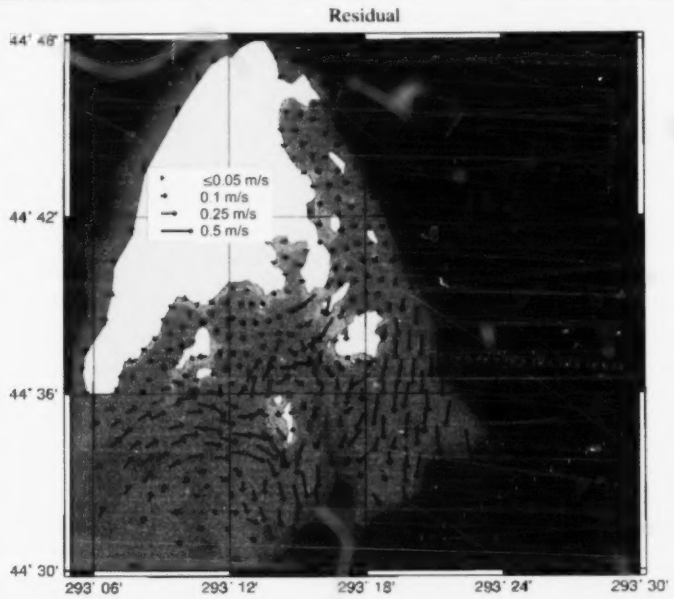
Slide 6



Comparison of model and observed M2 tide amplitde (radius) and phase (angle). 1 degree phase is approximately 2 minutes.

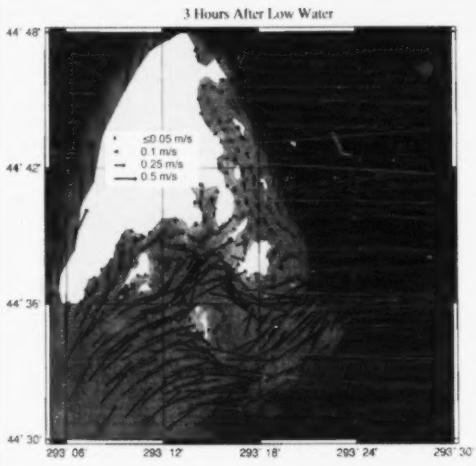
Appendix 6: Modelling currents in Grand Manan shallows
(17 February 2004, presented by D. Greenberg)

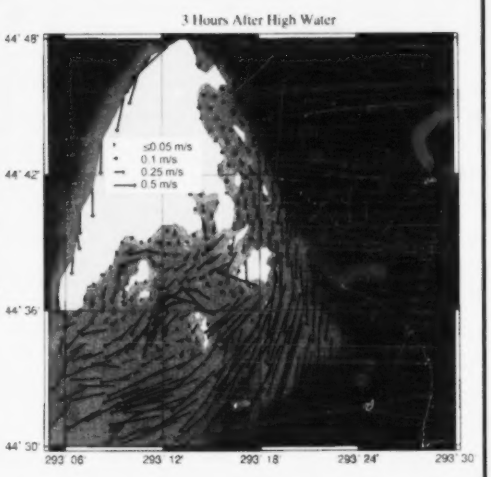
Slide 7



Model currents averaged over 1 tidal cycle

Slide 8

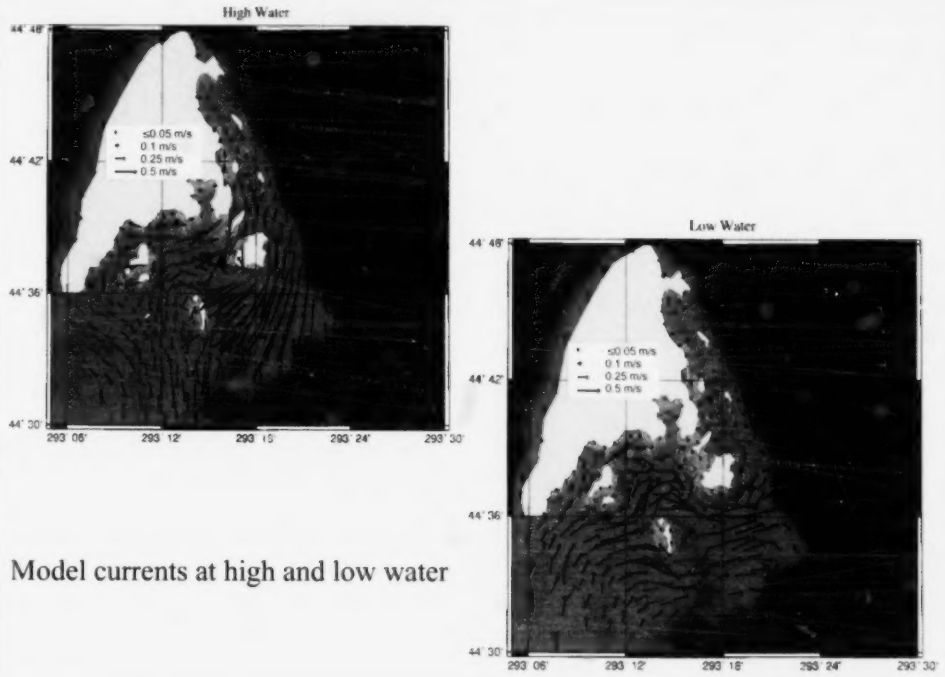




Model currents at peak flood
and peak ebb tide

Appendix 6: Modelling currents in Grand Manan shallows
(17 February 2004, presented by D. Greenberg)

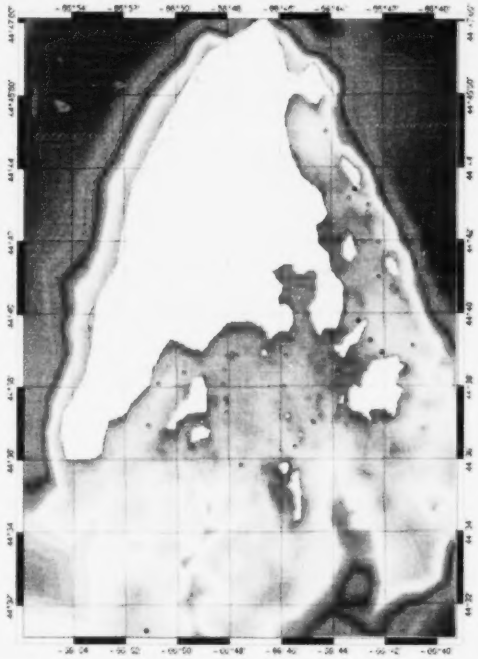
Slide 9



Model currents at high and low water

Slide 10

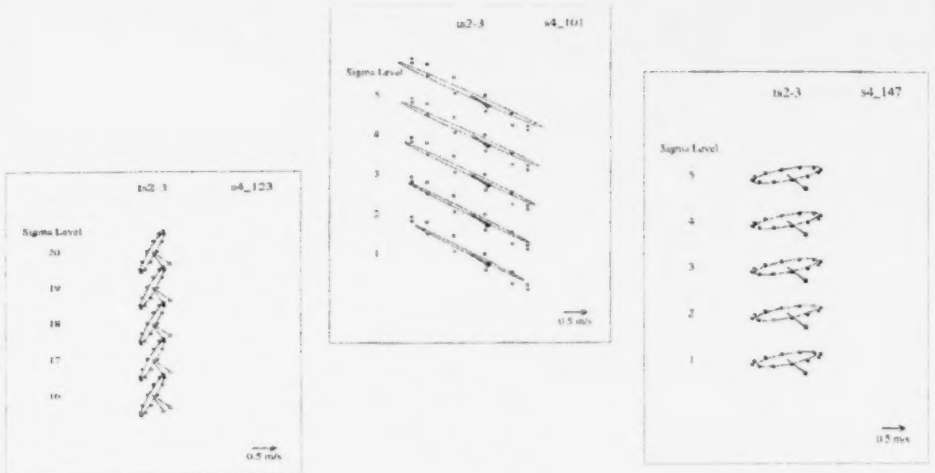
Locations of current meter observations



- ADCP meters
- S4 meters

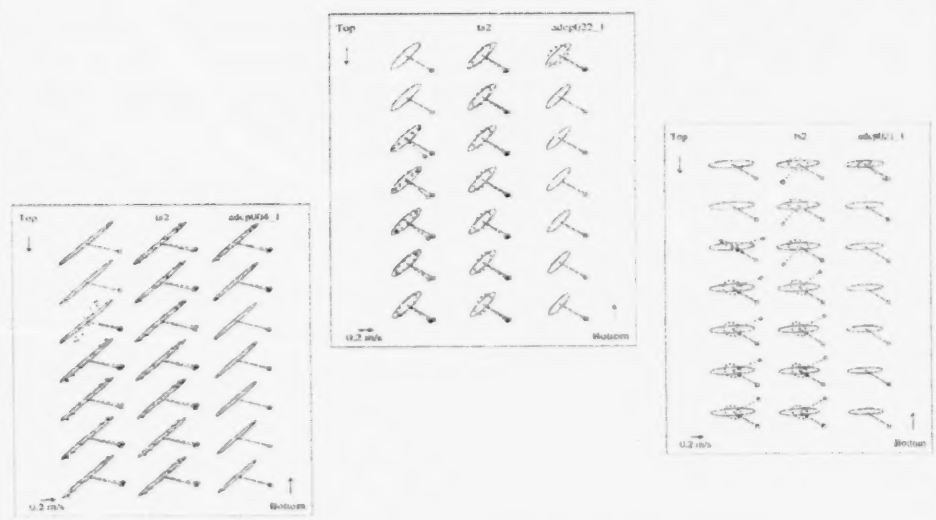
Appendix 6: Modelling currents in Grand Manan shallows
(17 February 2004, presented by D. Greenberg)

Slide 11



Comparisons of model (solid line) and s4 current meter ellipses and timing (straight lines).

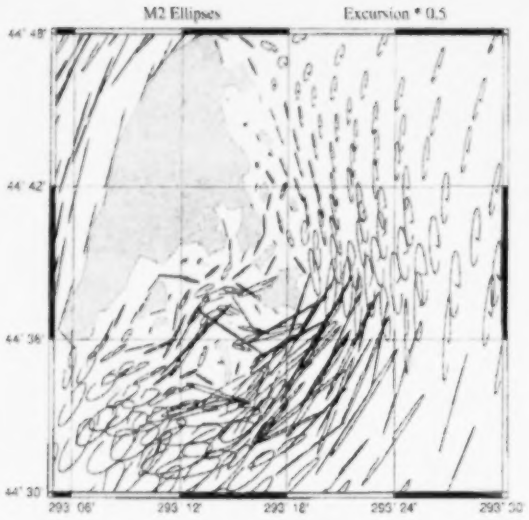
Slide 12



Comparisons of model (solid line) and adcp current meter ellipses and timing (straight lines).

Appendix 6: Modelling currents in Grand Manan shallows
(17 February 2004, presented by D. Greenberg)

Slide 13



Tidal ellipses drawn to half scale of excursion

Slide 14

Conclusions

We have a working model that is not perfect, but is capable of producing useful results.

Possible improvements include:

- more complex tides
- more complex winds
- density driven motions

Appendix 7: Water circulation and management of ISA in the southwestern New Brunswick salmon aquaculture industry (17 February 2004, presented by F. Page)

Slide 1

Water circulation and management of ISA in the southwestern New Brunswick salmon aquaculture industry

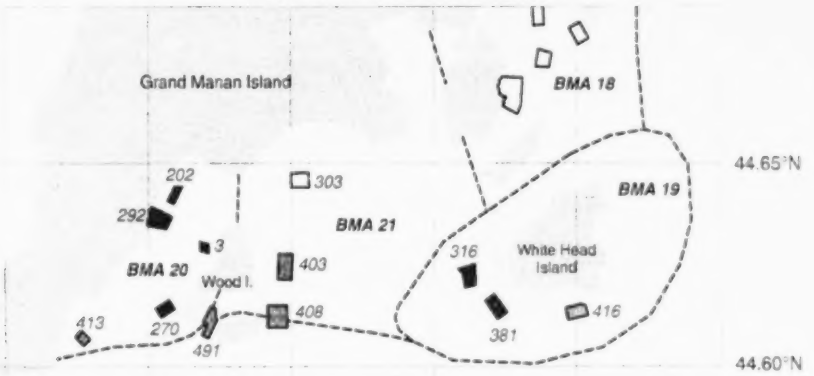
F.H. Page[1], B.D. Chang[1], R. Losier[1],
D. Greenberg[2] & P. McCurdy[1]

[1] Fisheries & Oceans Canada, St. Andrews Biological Station

[2] Fisheries & Oceans Canada, Bedford Institute of Oceanography

Slide 2

Southern Grand Manan



2000

- 7 farms within 3 BMAs; ~1.79M fish
- odd year-classes (black); even year-classes (white)

2003

- 5 new odd year-class farms authorised (grey);
- total of 12 farms ~3.69M fish

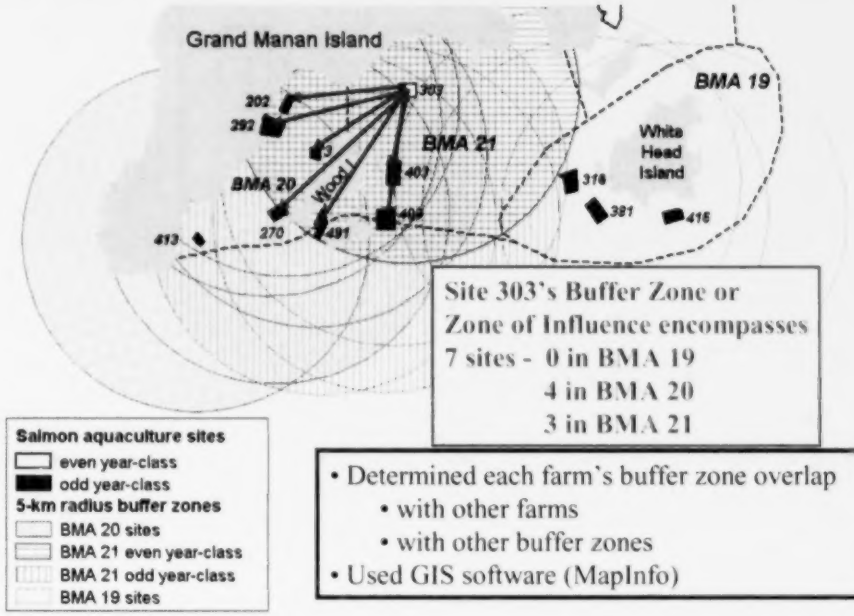
Concerns that the fish health management strategy may be ineffective due to uncertainties in the knowledge concerning:

- water exchange between sites
- effectiveness of the existing BMA boundaries

Appendix 7: Water circulation and management of ISA in the southwestern New Brunswick salmon aquaculture industry (17 February 2004, presented by F. Page)

Slide 3

Simple Approach: 5 km radius "buffer" zones

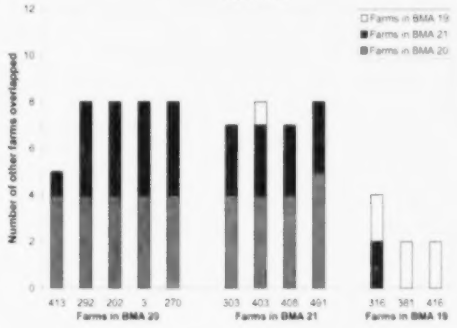


- Determined each farm's buffer zone overlap
  - with other farms
  - with other buffer zones
- Used GIS software (MapInfo)

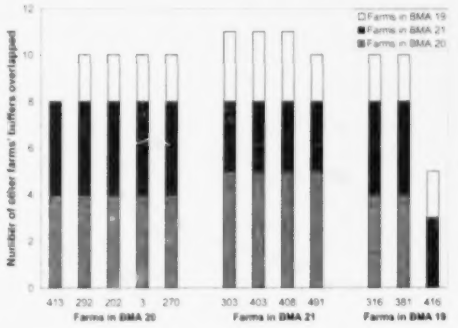
Slide 4

Summary of Overlaps: 5 km radius circular buffer zones

Overlap of 5 km buffer zone with other farms


Number of other farms overlapped
Farms in BMA 19
Farms in BMA 21
Farms in BMA 20
413 292 202 3 270
303 403 408 491
316 381 416
Farms in BMA 20
Farms in BMA 21
Farms in BMA 19

Overlap of 5 km buffer zones


Number of other farms' buffers overlapped
Farms in BMA 19
Farms in BMA 21
Farms in BMA 20
413 292 202 3 270
303 403 408 491
316 381 416
Farms in BMA 20
Farms in BMA 21
Farms in BMA 19

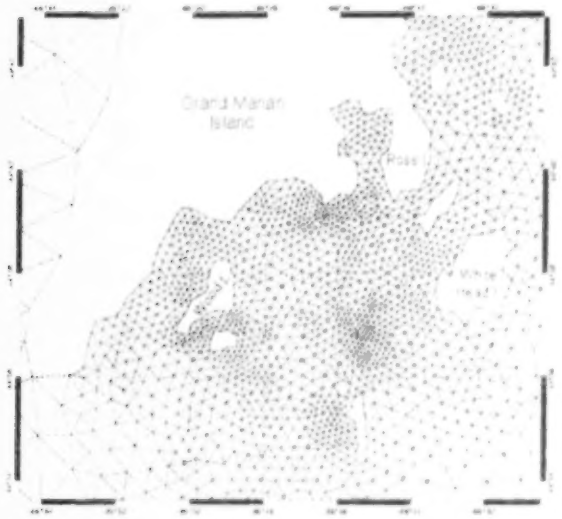
- Result: Extensive overlap and hence possible water exchange between farms within BMAs and between farms in different BMAs

- Interpretation: - farms and BMAs are not independent on tidal time scale
  - principles of BMA approach suggest 1 BMA rather than 3
  - *BMA 20 & 21 linked to each other but somewhat separate from BMA 19*

Appendix 7: Water circulation and management of ISA in the southwestern New Brunswick salmon aquaculture industry (17 February 2004, presented by F. Page)

Slide 5

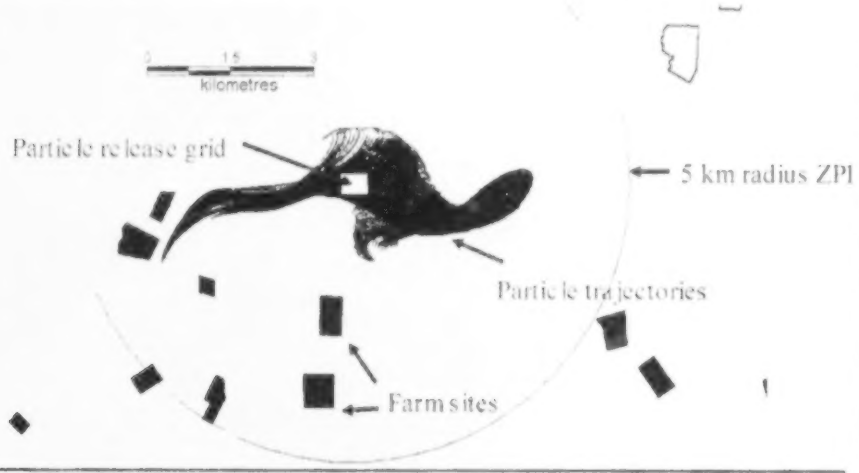
More Complex Approach: Model-derived tidal excursions



- 3D finite element circulation model
  - fully non-linear
  - inter-tidal drying
  - 21 sigma levels
  - ~50m horizontal resoultion
- driven by tides, winds and baroclinicity
- only used M_2 tide to date

Slide 6

Model-derived particle tracks over 1 tidal cycle i.e. tidal excursions

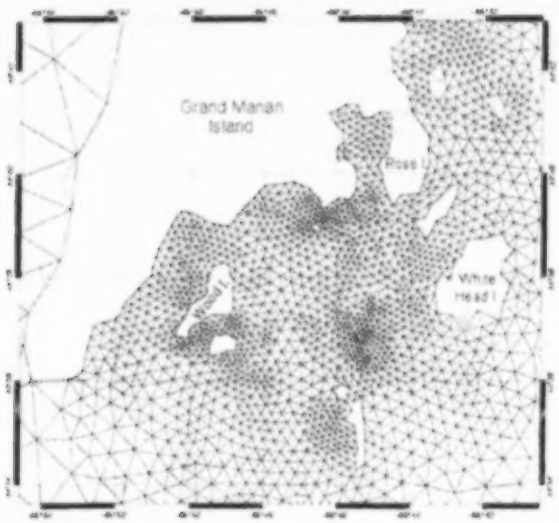


- *Released 36 "drogues" evenly spaced on a 200 m× 200m grid centred on each farm site*
- *Drogues released from each point at 1 hour intervals for 12 hours*
- *Each drogue followed for at least one tidal cycle (12.42 h)*
- *Tidal excursion estimated as area covered by all drogue tracks during 1 tidal cycle*
- Excursion not a circle and covers less area than circle

Appendix 7: Water circulation and management of ISA in the southwestern New Brunswick salmon aquaculture industry (17 February 2004, presented by F. Page)

Slide 5

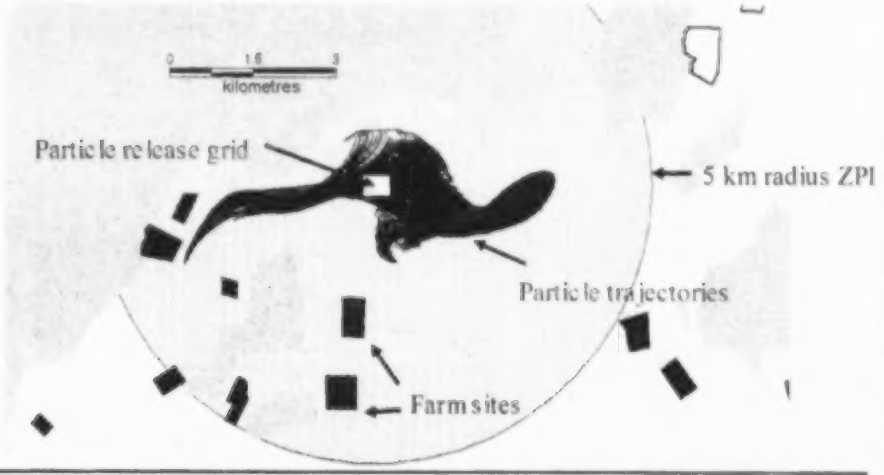
More Complex Approach: Model-derived tidal excursions



- 3D finite element circulation model
  - fully non-linear
  - inter-tidal drying
  - 21 sigma levels
  - ~50m horizontal resoultion
- driven by tides, winds and baroclinicity
- only used M_2 tide to date

Slide 6

Model-derived particle tracks over 1 tidal cycle i.e. tidal excursions

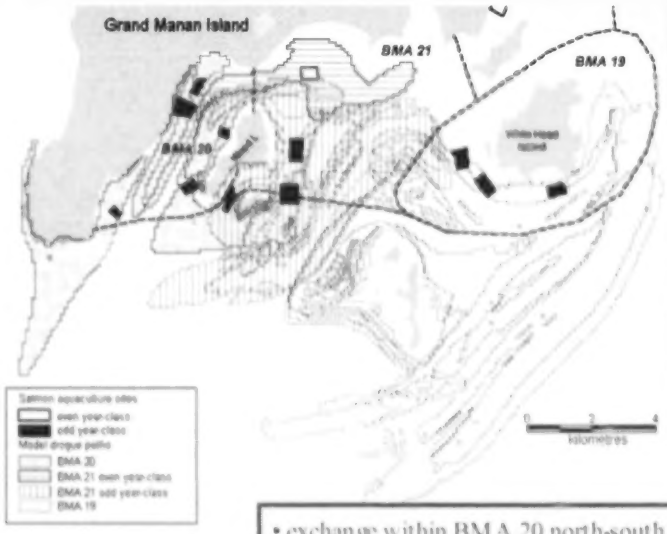


- *Released 36 "drogues" evenly spaced on a 200 m× 200 m grid centred on each farm site*
- *Drogues released from each point at 1 hour intervals for 12 hours*
- *Each drogue followed for at least one tidal cycle (12.42 h)*
- *Tidal excursion estimated as area covered by all drogue tracks during 1 tidal cycle*
- Excursion not a circle and covers less area than circle

Appendix 7: Water circulation and management of ISA in the southwestern New Brunswick salmon aquaculture industry (17 February 2004, presented by F. Page)

Slide 7

Model-derived tidal excursions for all fish farms (1 tidal cycle)



Project team still digesting results

Results suggest:
- overlaps less extensive than estimated by circles
- chain of overlaps not broken

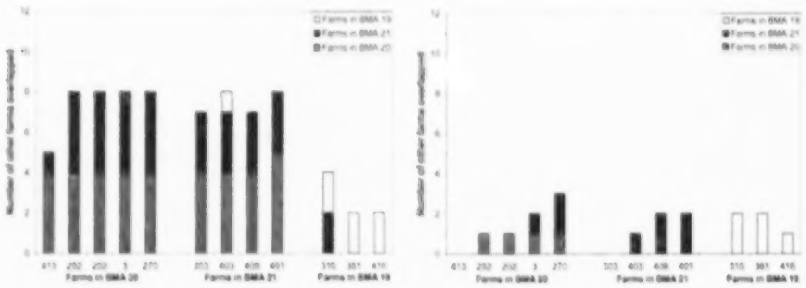
- exchange between BMA 19 farms
- BMA 19 farms separate from farms in other BMAs

- exchange within BMA 20 north-south rather than east-west
- BMA 20 influences BMA 21 more than vice versa
- site 303 influenced mainly by 1 site (003) in BMA 20
- site 303 influences BMA 20 (sites 202 & 292)

Slide 8

Comparison of 5 km circular buffer zones and model-derived tidal excursions

1) Overlap with other farms



5 km circular buffer zones | Model Tidal excursions

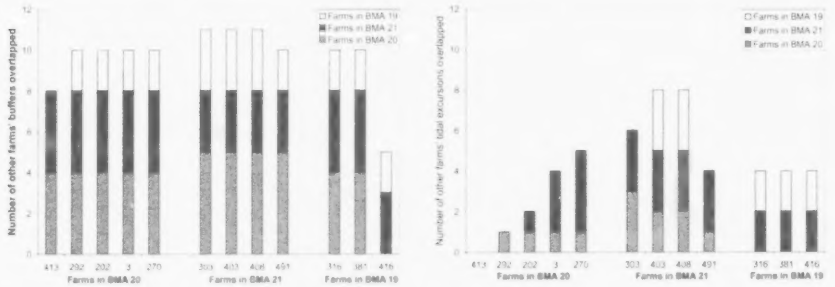
- Model results in considerably lower estimates of overlap.
- Number of farms in tidal overlap ZPI decreases from ~4-8 to ~1-2 in BMAs 20-21

Appendix 7: Water circulation and management of ISA in the southwestern New Brunswick salmon aquaculture industry (17 February 2004, presented by F. Page)

Slide 9

Comparison of 5 km circular buffer zones and model-derived tidal excursions

2) Overlap with other farms' buffer zones or tidal excursions

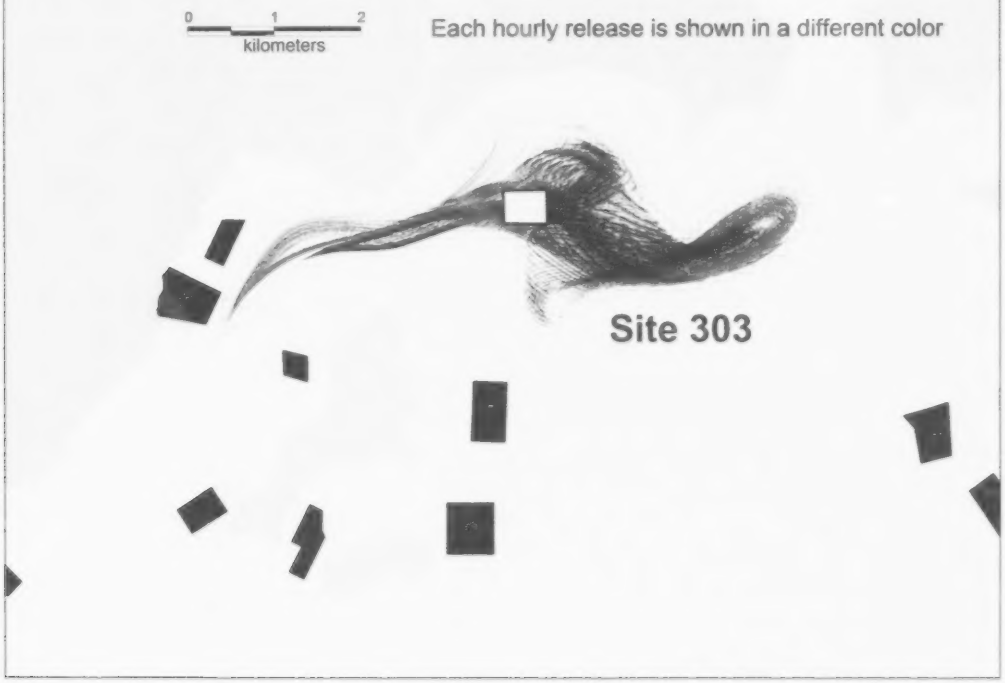

Number of other farms' buffers overlapped
Farms in BMA 19
Farms in BMA 21
Farms in BMA 20
413 292 202 3 270
Farms in BMA 20
303 403 408 491
Farms in BMA 21
316 381 416
Farms in BMA 19
Number of other farms' tidal excursions overlapped

5 km circular buffer zones

Tidal excursions

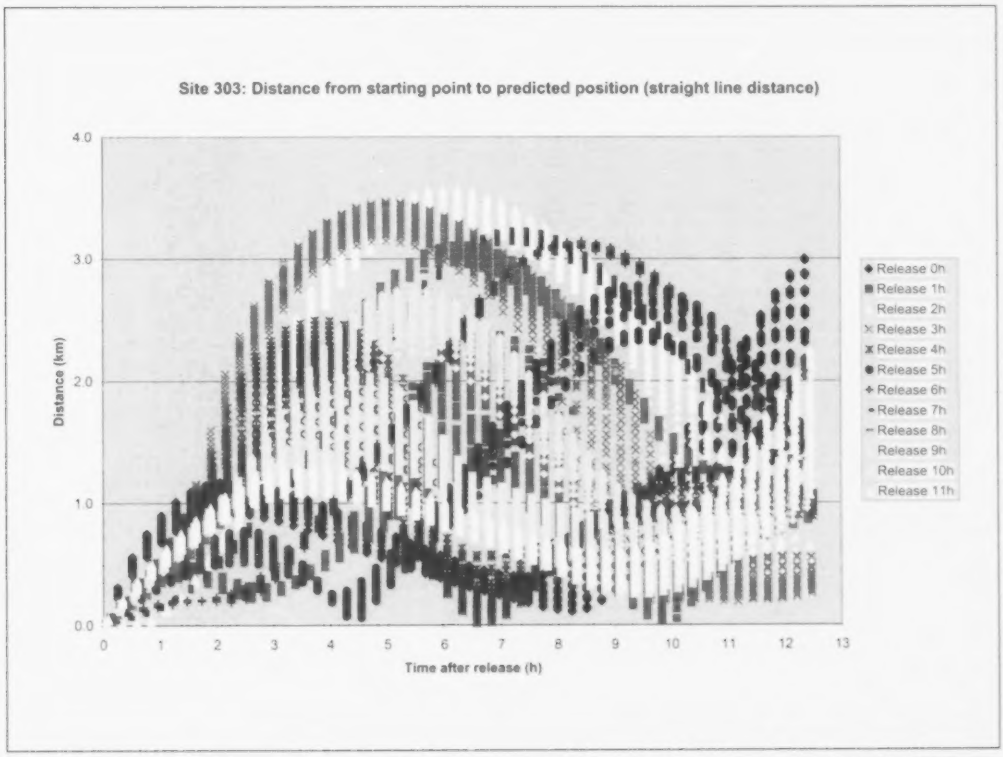
- Model results in considerably lower estimates of overlap, especially for sites in BMA 20 and 19.

Slide 10

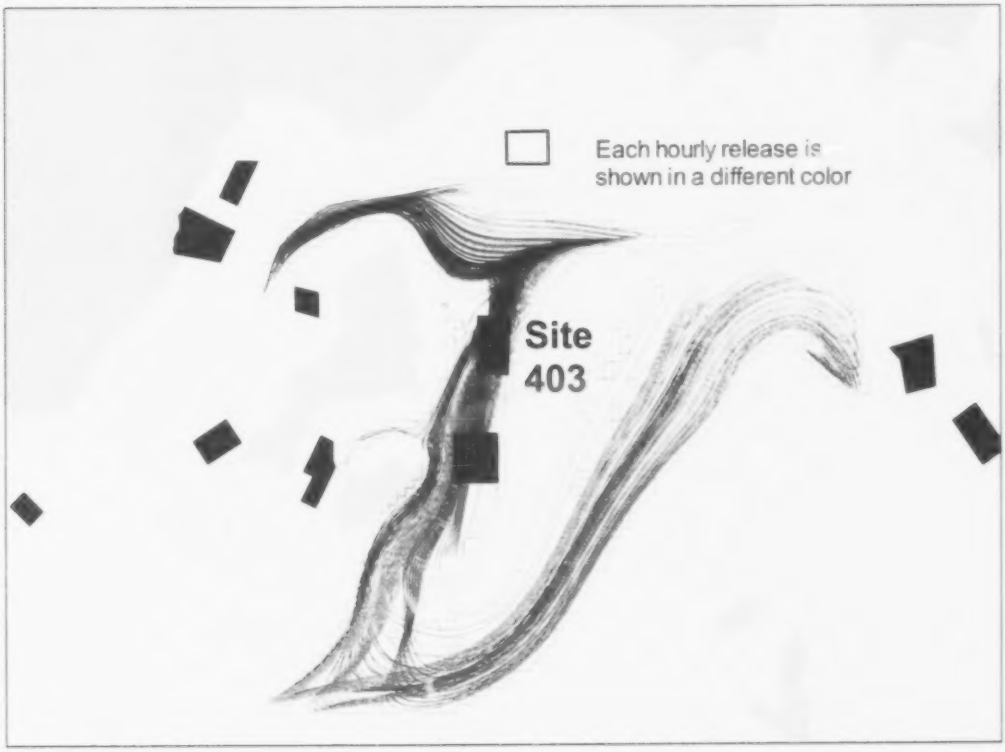


Appendix 7: Water circulation and management of ISA in the southwestern New Brunswick salmon aquaculture industry (17 February 2004, presented by F. Page)

Slide 11

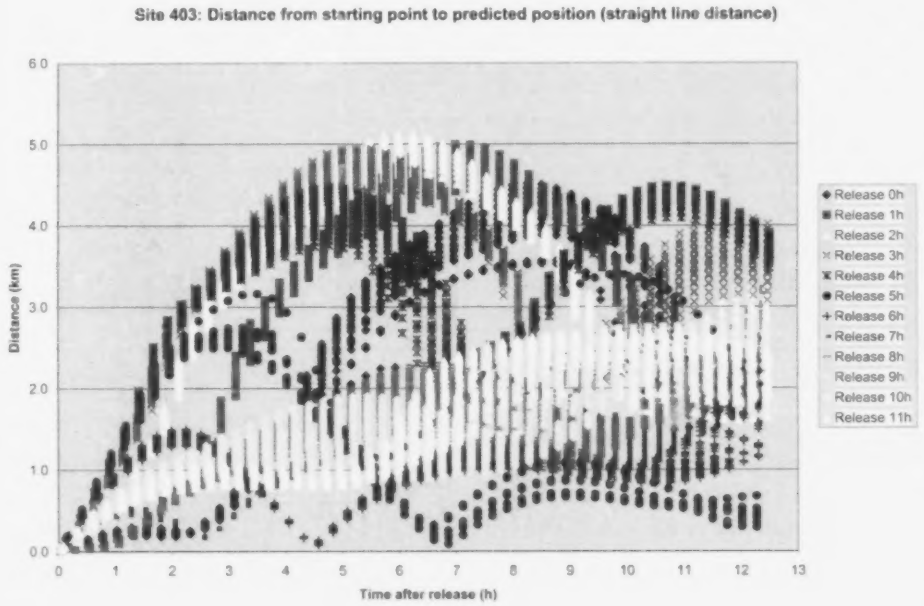


Slide 12



Appendix 7: Water circulation and management of ISA in the southwestern New Brunswick salmon aquaculture industry (17 February 2004, presented by F. Page)

Slide 13



Slide 14

Conclusions

- Using 5 km circular buffer zones shows considerable overlap among farms in southern Grand Manan
- Circulation model indicates that water circulation pattern is complex:
  - tidal excursion area is not circular shape
  - tidal excursion area is often smaller in area than 5 km circular zone
  - although a chain of overlap still is still indicated there is considerably less overlap among sites than using simple circular zones
- This approach is viewed as being useful in helping to estimate interactions between sites.
- The approach highlights the need to consider the cost-benefit trade-offs between the simple but cheap and quick approach of 5km circular buffer zones with that of the more complex, expensive and time consuming approach of developing and using models.

Appendix 8: Notes on the final project meeting's discussions and recommendations (17 February 2004, compiled by B. Chang and F. Page)

- Is there water exchange between sites MF-303 and MF-403 (and other sites)?
  - ⇒ On a scale of one tidal excursion, there is little exchange between sites MF-303 and MF-403.
  - ⇒ However, under certain wind conditions there can be more exchange between these sites (i.e. southerly movement from site MF-303 toward site MF-403, but not in a direct straight line).
  - ⇒ There is considerable water exchange between sites MF-403 and MF-408.
  - ⇒ What would happen if site MF-303 was shifted eastward?
    - We have no field data and we have not run the model from this area, but it would probably decrease the exchange between site MF-303 and Seal Cove; however, it might increase the interaction of site MF-303 with the White Head Island sites (BMA 19).
    - ***Update***: model has now been run and confirms that if site MF-303 was moved eastward (about 2 km), the new tidal exchange area would not enter BMA 20 (Seal Cove), but would now overlap with two of the sites in BMA 19.

- Is this exchange of concern?
  - ⇒ We don't know what the effective dose is for ISA.
  - ⇒ We don't yet have good information on survival of the ISA virus in seawater.
  - ⇒ Water exchange could facilitate movement of sea lice, especially planktonic stages; however it is not certain if the planktonic stages can transmit ISAV (adult lice are known carriers of ISAV, but are not planktonic and therefore cannot move far).
  - ⇒ Improved biosecurity has greatly reduced the incidence of ISA, but oceanography is still considered to be a potentially important factor in the spread of disease.

- What would we suggest for BMA boundaries in this area?
  - ⇒ Oceanographic work suggests that BMAs 20 and 21 should be combined; BMA 19 shows some separation from BMAs 20 and 21.
  - ⇒ Site MF-303 is somewhat separated from other sites in BMAs 20 and 21, so its current status as the only even year-class site could be maintained.

- Is the use of one tidal excursion appropriate?
  - ⇒ One tidal excursion is used in Norway and Scotland for ISA management.
  - ⇒ The tidal excursion concept is more realistic than straight line separation distances or circular buffer zones separating sites, and is worth the extra effort and expense.
    - Water often does not move in a straight line between sites; e.g. the straight line distance between sites MF-303 and MF-403 is about 2 km, but the effective distance for water travelling between these sites is much greater.
    - Tidal excursions are not usually circular in shape.

Appendix 8: Notes on the final project meeting's discussions and recommendations
(17 February 2004, compiled by B. Chang and F. Page)

- What did the project achieve?
  - Did we develop a better understanding of the water circulation in the southern Grand Manan area?
    - ⇒ Yes.
    - ⇒ Field data and computer model generally agree.
  - Did we establish a closer link between oceanographers and fish health specialists?
    - ⇒ Yes.
    - ⇒ We need to know the oceanography, but we also need to know more of the fish health factors.

- What other work should be done? Note that the project funding terminates in March 2004.
  - ⇒ It would be useful to have plots of drogues, with each hourly release shown separately, for every farm site.
  - ⇒ Site specific residence times: how long does it take for particles to leave a site? Also, bay residence times.
  - ⇒ What percent of particles from a site are going to another area: e.g. what percent of particles from site MF-303 go into Seal Cove; or how many of the hourly drogue releases will intercept a certain site or area?
  - ⇒ Similar work should be done in other fish farming areas of southwest New Brunswick.
  - ⇒ Work is on-going with US counterparts in Western Passage.
  - ⇒ Need to meet with Larry Hammell to discuss his epidemiological findings.
  - ⇒ More oceanographic work linked to current disease outbreaks: e.g. investigations into why some isolated sites become infected; investigations on links between oceanography and sea lice dispersal.

Appendix 9: List of project publications, reports, presentations, and meetings

Publications generated by the project

Greenberg, D.A., Shore, J.A., Page, F.H., and Dowd, M. 2004. Modelling embayments with drying intertidal areas for application to the Quoddy region of the Bay of Fundy. Ocean Model. (accepted for publication).

Greenberg, D.A. 2002. Overview of oceanographic information and approaches: modelling currents for Grand Manan aquaculture. p. 31-35 *In* F. Page and B. Chang (eds.) Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: report of the initial project meeting, 18 December 2001. Can. Tech. Rep. Fish. Aquat. Sci. 2409: vii + 48 p.

Halse, N. 2002. Rationale for the development of Bay Management Areas for the salmon farming industry in New Brunswick. p. 13-14 *In* F. Page and B. Chang (eds.). Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: report of the initial project meeting, 18 December 2001. Can. Tech. Rep. Fish. Aquat. Sci. 2409: vii + 48 p.

McGeachy, S. 2002. Atlantic salmon farming in Grand Manan: an overview. p. 10-11 *In* F. Page and B. Chang (eds.) Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: report of the initial project meeting, 18 December 2001. Can. Tech. Rep. Fish. Aquat. Sci. 2409: vii + 48 p.

McGeachy, S. 2002. History of infectious salmon anaemia (ISA) in New Brunswick. p. 15-17 *In* F. Page and B. Chang (eds.) Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: report of the initial project meeting, 18 December 2001. Can. Tech. Rep. Fish. Aquat. Sci. 2409: vii + 48 p.

Page, F.H., Chang, B.D., Losier, R., Greenberg, D., and McCurdy, P. 2004. Water circulation and management of ISA in the southwest New Brunswick salmon aquaculture industry. Aquacult. Assoc. Can. Spec. Publ. 8: 64-68 (in press).

Page, F.H., Stephenson, R.L., and Chang, B.D. 2004. A framework for addressing aquaculture–environment–fisheries interactions in the Bay of Fundy. Aquacult. Assoc. Can. Spec. Publ. 8: 69-72 (in press).

Page, F.H. and Chang, B.D. (Editors). 2002. Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: report of the initial project meeting, 18 December 2001. Can. Tech. Rep. Fish. Aquat. Sci. 2409: vii + 48 p.

Page, F. 2002. Overviews of oceanographic information and approaches: hydrographic, current and dispersal concepts and measurements p. 19-31 *In* F. Page and B. Chang (eds.) Fish Health and Oceanography Project of the Aquaculture Collaborative Research and

Appendix 9: List of project publications, reports, presentations, and meetings

Development Program: report of the initial project meeting, 18 December 2001. Can. Tech. Rep. Fish. Aquat. Sci. 2409: vii + 48 p.

Project Progress Reports

Page, F.H. 2004. Aquaculture Collaborative Research and Development Program Final Project Report for project MG-01-06-014 on Fish Health and Oceanography submitted to the ACRDP Gulf-Maritimes Regional Management Committee, 13 p.

Page, F.H. 2003. Aquaculture Collaborative Research and Development Program Annual Project Report for project MG-01-06-014 on Fish Health and Oceanography submitted to the ACRDP Gulf-Maritimes Regional Management Committee. Report covered the fiscal year 2002-2003

Page, F.H. 2002. Aquaculture Collaborative Research and Development Program Progress Status Report for project MG-01-06-014 on Fish Health and Oceanography submitted to the ACRDP Gulf-Maritimes Regional Management Committee. Report covered the period fall 2001 to September 2002.

Project Meetings:

Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: Final Project Team Meeting, held at the St. Andrews Biological Station, Conference Centre, 17 February 2004.

Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: Mid-Project Team Meeting, held at the St. Andrews Biological Station, Conference Centre, 3 October 2002.

Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program: Initial Project Team Meeting, held at the New Brunswick Salmon Growers' Association, Letang, NB, 18 December 2001.

Formal Presentations:

Page, F.H. 2004. An introduction to a potential decision support tool for assisting in the generation of scientific advice for the coastal zone. Bay of Fundy Stakeholders Forum, Delta Brunswick Hotel, Saint John, NB, 13 May 2004. The major example used in the presentation was the ACRDP Fish Health and Oceanography project.

Page, F.H., Chang, B.D., and Greenberg, D.A. 2004. Aquaculture Collaborative Research and Development Program (ACRDP) Final Project Report for project MG-01-06-014 on Fish Health and Oceanography presented to the ACRDP Gulf-Maritimes Regional Management Committee on 10 May 2004, DFO Gulf Fisheries Centre, Moncton, NB.

Appendix 9: List of project publications, reports, presentations, and meetings

Page, F., Stephenson, R., and Chang, B. 2004. An introduction to the coastal zone situation and a framework and approach for generating scientific advice for decision making (a DSS). A presentation made at the Workshop on the Far-fields effects of Aquaculture, held at the Bedford Institute of Oceanography, January 2004.

Page, F., Stephenson, R. and Chang, B. 2004. An introduction to the coastal zone situation and a framework and approach for generating scientific advice for decision making (a DSS). A presentation given to the Eastern Scotian Shelf Integrated Management Team at the Bedford Institute of Oceanography in December 2003 and to a general audience as part of the Marine Environmental Sciences Division lunch-time seminar series in December 2003.

Page, F. 2003. An introduction to a framework for generating scientific advice and the Applied Coastal Ecosystem Science (ACES) program at the St. Andrews Biological Station (SABS). A seminar given to DFO staff in Ottawa in November 2003.

Page, F.H., Chang, B.D., Losier, R., Greenberg, D., and McCurdy, P. 2003. Water circulation and management of ISA in the southwest New Brunswick salmon aquaculture industry. Aquaculture Association of Canada Annual Conference, Victoria, BC, October 2003.

Page, F.H., Stephenson, R.L., and Chang, B.D. 2003. A framework for addressing aquaculture–environment–fisheries interactions in the Bay of Fundy. Aquaculture Association of Canada Annual Conference, Victoria, BC, October 2003.